Fixing or Transferring Environmental Problems in the Transport Sector?

Walnum, Hans Jakob

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BY
HANS JAKOB WALNUM

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DENMARK

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Hans Jakob Walnum

AALBORG UNIVERSITY
DENMARK

Dissertation submitted

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Thesis submitted:	July 3, 2015
PhD supervisor:	Associate Prof. Søren Løkke Aalborg University
Assistant PhD supervisor:	dr. Carlo Aall Western Norway Research Institute
PhD committee:	Prof. David Banister Oxford University
	PhD. Aud Tennøy Intitute of Transport Economics
	Prof. Inge Røpke Aalborg University
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CV

Hans Jakob is cand.polit in political science from NTNU 2005. He has been teaching at Sogndal College and Sogndal University College, he has also been working as an advicer for IW (inclusive worklife) enterprises in Sogn og Fjordane. Since 2008 he has been working as a researcher in the environmental group at Western Norway Research Institute (WNRI). He has worked with transport, sustainable mobility, life cycle analysis and transference of environmental problems. From 2011 he has been enrolled as a PhD student at Aalborg University (AAU) working with a thesis on transfer effects and transport.

ENGLISH SUMMARY

A central feature in the history of environmental problems is the issue of transfer effects; many proposed solutions cause new environmental problems. For example, increased technological efficiency and innovation are frequently discussed as strategies to mitigate GHG emissions and energy use in the transport sector. The research in this thesis indicates that the idea of a technological and policy quick-fix is highly problematic because a proposed solution by policy, innovation or technology often transfers the environmental problem to other life cycle stages, to other emissions categories, to other countries, or to increased demands at the macro level when making an efficiency improvement at the micro level.

This PhD thesis examines three "transfer effects": rebound effects, trade-offs effects and geographical transfer effects (also called carbon leakage) in the transport sector. The thesis contributes with a covering essay on this topic discussing the findings from the five papers included in the thesis.

DANSK RESUME

Forskydningseffekter i transportsektoren med løsning af et miljøproblem der fører til miljøbelastninger andetssteds er det tematiske fokus i denne avhandling. Et centralt punkt indenfor miljøproblemer har historisk set været at mange løsningsforslag blot skaber nye miljøudfordringer andre steder. Øget teknologisk effektivitet og innovation bliver eksempelvis ofte nævnt som strategier der kan minimere gasudledning og reducere energiforbruget i transportsektoren, men en teknologisk eller politisk ”hurtigløsning” er yderst problematisk, fordi de foreslåede løsninger blot flytter de miljømæssige udfordringer til andre livscyklusstadier, andre udledningskategorier, til andre sektorer eller andre lande. Det skaber et paradoks, som der må tages højje for i fremtidig transportplanlægning.

Denne PhD afhandling undersøger tre “forskydnings effekter” i transportsektoren: miljømæssig bagslag, geografiske skift samt afvejning af eller skift i miljøpåvirkninger. Der præsenteres fem artikler omkring dette emne.

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1. INTRODUCTION

Worldwide, we are currently consuming resources faster than they can be regenerated and creating emissions and waste faster than the environment can absorb. In a typical year, we globally consume the equivalent of 1.5 planet's-worth of productive biological capacity to support our lifestyles (Butchart et al., 2010), and we are far from meeting current environmental targets in the short run. To ensure that the world average global temperature does not rise more than 2° Celsius above pre industrial levels, the atmospheric CO_2 concentrations would have to stay below approximately 450 parts per million (ppm). To achieve this, it has been estimated that by 2020, developed countries need to reduce greenhouse gas (GHG) emissions by 25 to 40% of 1990 levels (IEA, 2010; IPCC, 2007) and developing countries need to reduce emissions by 15 to 30% relative to business-as-usual (Den Elzen and Höhne, 2008). In the longer term, the EU has, for example, set its target to reduce GHG levels by at least 80% by 2050 compared to 1990 levels. However, GHG emissions targets have not accounted for the need to reduce GHG emissions early on the road towards 2050. The more we postpone reduction, the more we will need to reduce. This implies the need for a more dramatic reduction in GHG emissions. To achieve such a reduction in both the short and the long term, energy use and GHG emissions from transport must be reduced. Worldwide, the transport sector produced 7.0 $GtCO_2eq$ of direct GHG emissions, which corresponds to approximately 23% of total energy-related CO_2 emissions. From 1970 to 2010, the direct energy use associated with transport has grown by 250% worldwide—a growth rate that is higher than any other sector (Sims et al., 2014). Regionally, such as in the EU, the transport sector was responsible for 25% of the energy-related GHG emissions. Although the recently adopted EU target is to reduce GHG emissions levels by 80–95% from 1990 levels by 2050, the European Commission stated that the goal for the transport sector is 60% (European Commission, 2011). The reason for a lower goal in the transport sector is probably because of its complexity and level of conflict. Current scientific discourse indicate that there is widespread agreement that existing transport policies fail to address the growing problems of congestion and GHG emissions in transport, thus policy changes will be inevitable (Givoni and Banister, 2013; Gössling and Cohen, 2014). It could be argued that to do anything with GHG emission from transport is a complex challenge because of its embeddedness to most of the sectors in society and the role transport play for continuous economic growth (Givoni, 2013).

This thesis contributes to the scientific and political discourse of sustainable mobility. Since the 1987 report "Our Common Future" (World Commission on Environment and Development, WCED 1987) launched sustainable development as a primary goal for society, scientific and political discussions about its definition and how it can be achieved have ensued. I define sustainable development in the same terms as the WCED (1987). Basically sustainable development is development that "meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED, 1987). Following the general term sustainable development the concept *sustainable mobility* was launched by the Commission of the European Union in a 1992 green paper (EUCOM, 1992). The concept evoked considerable interest, both in politics and science. I primarily examine how wealthy countries, such as Norway and the United States as well as countries and regions in the EU and in the Organization for Economic Cooperation and Development (OECD), can achieve sustainable mobility in the transport sector by also taking into account the problems related to rebound effects, trade-off effects, and geographical transfer effects. In the thesis I am mainly concerned with the environmental part of sustainability with a focus on energy use and greenhouse gas (GHG) emissions. Høyer (1999) identified three main strategies that are used to achieve sustainable mobility; efficiency, substitution, and volume reduction. I will use these strategies as a point of departure to discuss their relationship to transfer effects.

(1) The efficiency strategy is based on the idea that environmental problems caused by transport can be improved by developing new and more efficient technologies to replace old, inefficient, and polluting materials and methods;

(2) The substitution strategy argues for changes to less polluting means of transport;

(3) The volume reduction strategy argues that efficiency and substitution are not sufficient, we must fundamentally change behavior and consumption patterns. People must travel less, and freight volumes must decrease.

A core controversy in the scientific and political discourse about sustainable development is whether environmental sustainability can be achieved through technological improvements and changes in consumption patterns or whether the total volume of consumption must be reduced. Curbing energy use and GHG emissions by (1) efficiency and (2) substitution—could be translated into changing the growth of transport volumes; this position can be considered to be consistent with ecological modernisation. Ecological modernisation is a position within the social science and the ecological discourse that believe it is possible to make a decoupling between environmental harms and the economy by technological progress (Spaargaren et al., 2000). In the transport sector many policies in line with ecological modernisation are found such as electrifying the transport sector. A reduction in (3) volume of transport is more in line with a "degrowth" position, which argues for a rethinking of economic growth (Schneider et al., 2010). Degrowth has evoked considerable interest in the academic discourse and to some extent also connected to transport (Moriarty and Honnery, 2013). I will compare the positions with regard to how they handle transfer effects.

The covering essay seeks to increase the knowledge of why energy use and GHG emissions in the transport sector keep rising despite technological and policy measures for their mitigation. Many proposed solutions cause new environmental problems as the problems are moved from one place to another (Høyer, 2002). Often a proposed solution by policy, innovation, or technology will result in transferring the environmental problem, In the covering essay, transfer effects include environmental problems shifting along the life cycle of products, trade-offs between emissions categories, and a shift in geographical location of emissions. The following three "transfer effects" are examined: 1. rebound effects, 2. environmental trade-off effects, and 3. geographical transfer effects.

Studying rebound effects shows that efficiency measures taken at the micro level do not necessarily lead to society-wide reduction. Despite improvements in intensity of grams of CO_2 per kilometer for passenger cars in the EU and the US, energy reduction has been outweighed by an increase in the total kilometers travelled and by the sales of larger vehicles (Holden, 2012). This result might be explained by rebound effects associated with systemic and behavioral responses. For example, the cost savings from buying a fuel-efficient car could enable a person to drive farther (a direct rebound effect) or to purchase other energy-consuming activities. However, the extant literature (Sorrell, 2007; Sorrell and Dimitropoulos, 2007) has mainly explained rebound effects in terms of economic theory. To fully understand rebound effects, I argue that an interdisciplinary approach must be taken. It is important to understand the rebound effect beyond an explanation through income and substitution effects. Structures (physical urban structures, economic systems, and political systems) as well as dimensions other than money saved will influence the rebound effect (environmental awareness, habits, and lifestyles).

Investigating trade-offs or shifting environmental impacts are done by life-cycle and energy-chain analyses, which could be considered studies of indirect rebound effects (Sorrell, 2007), looking at products from cradle-to-grave. Both analyses compare products at the micro level and identify environmental hotspots during production that can be used to study fuels and transport systems or to compare transport systems (Høyer, 2002). They teach an important lesson: there are always trade-offs in, for example, the usage of alternative fuels because such trade-offs merely change instead of reduce the total overall environmental impact. Using alternative vehicle technology generally reduces the environmental impact in one category (GHG emissions), but this lone positive impact is counteracted by negative environmental impacts in other categories (such as increased total energy use or environmentally harmful land use). They can also involve a shift during the life cycle from the vehicle to the production site and the distribution process (Holden, 2012).

Geographical transfer effects means in this thesis a transfer of GHG emissions to other countries and places (Aall and Hille, 2010; Helm et al., 2007; Hertwich and Peters, 2009; Munksgaard and Pedersen, 2001). How this accounting is performed affects transport-emission results. There is a need for understanding similarities and differences between the transfer effects and why such effects have been overlooked in policy making. Finally, I will discuss ways to mitigate these effects.

The following explicit research questions are addressed in the covering essay:

1. To what extent can transfer effects explain why energy use and GHG emissions in the transport sector have kept rising?
2. What are the similarities and differences between the three transfer effects?
3. To what extent have transfer effects been overlooked in policy making, and what could be done to mitigate them?

Table 1 summarizes the contributions of various papers to the overarching research question as well as to which sustainable mobility strategy and perspective—degrowth or ecological modernization—the paper is mostly associated with. The answers to research questions 2 and 3 are mostly cross-cutting between the papers and needs collected contributions from each one.

Table 1 Paper's contribution to the overarching research question

Paper	**Contribution to the overarching research question:** *To what extent can transfer effects explain the continual increase in energy use and GHG emissions in the transport sector?*	**Description**
1. CO_2 emissions from China's exported freight	Investigates geographic transfer effects and CO_2 emissions associated with international transport, using China's exported freight as an example.	Criticises the lack of proper accounting of GHG emissions related to international transport. Mostly associated with a degrowth position.
2. Energy chain analysis of passenger car transport	Discusses the trade-off between energy and GHG emissions for conventional fuels and powertrains from a life cycle perspective.	Mostly associated with ecological modernization and the efficiency strategy. This analysis is based on a "per unit of emissions" level. Understanding of the energy use and GHG emissions associated with the passenger car transport system
3. Rebound effects: The missing link in explaining why sustainable mobility has not been achieved?	Illustrates different disciplinary positions found within the rebound discourse using examples from previous research about rebound effects and transport.	Discusses the limitations with strategies that aim to curb energy use and GHG emissions. Associated with a degrowth postions.
4. Does driving behavior matter? An analysis of fuel consumption in heavy duty trucks	Addresses the influence of fuel consumption at the business level and how companies can reduce fuel consumption by using onboard fleet management software.	Associated with the efficiency strategy and ecological modernization; looks at the company level.
5. Driver and response model for Norwegian road freight transport in the period 1993-2013.	Looks at what affects energy use at the macro level for freight transport; discusses rebound and similar effects connected to responses.	Consistent with the degrowth position for curbing energy use and GHG emissions from road freight transport. Concludes that decoupling and dematerialization are not found in the period of investigation (1993–2013).

The analysis of papers 4 and 5 (Table 1) must be understood together, since one paper looks at what influences fuel consumption at the company level while the other focuses on the macro level. Measures intended to reduce energy use could vary across the micro and macro levels; solutions to micro level problems are not necessarily environmentally benign from a macro perspective when taking behavioral and systemic effects into consideration (Giampietro and Mayumi, 2008). I discuss why fuel savings at the micro level would not be transferable to the macro level. For example, if the micro analysis pointed to infrastructure improvements in reducing truck companies' fuel consumption, then taking into account generated traffic and induced travel as well as life cycle emissions would counteract some or all of the environmental gains at the macro level (Strand et al., 2009).

In this covering essay, I study important common features underlying the five papers in more detail to examine what they say about transfer effects and transport as well as the implications of the findings when taken together.

1.1 STRUCTURE OF THE COVERING ESSAY

The introduction set the stage for the covering essay by describing the challenge connected to GHG emission reduction in the transport sector, as well as an introduction of strategies and different viewpoints on how to mitigate them. The introduction also gives a definition of the three transfer effects. I also give a brief introduction of the main finding in each of the five papers.

I then go over to the theoretical part which consists of chapter 2 and 3. Chapter 2 is an introduction in how to understand the growth in transport volumes and the complexities associated with the transport sector. My main emphasis is to gain an understanding of the role of transfer effects in the transport sector. In chapter 3 I describe the position of sustainable development and sustainable mobility, they have for a long time dominated the environmental discourse. For my covering essay I find it very useful to discuss which strategies could be used to reach the goal of sustainable development and sustainable mobility when transfer effects also are taken into account. In the extension of this I describe and contrast the ecological modernisation and degrowth positions. They have different viewpoint on how to solve environmental problems in general, and in particular in the transport sector. The two positions also treats transfer effects differently.

The philosophical basis for my research and methodological part are presented in chapter 4 and 5. In chapter 4 I give an introduction to critical realism, which has influenced the perference for non-reductonism and interdiciplinary perspecitves in the covering essay and the papers. I find critical realism useful with regard to analysing and understanding transfer effects. In chapter 5 I reflect upon strengths and weaknesses with the method used in the different papers.

In chapter 6-8 I discuss the cross synthesing research questions by applying findings from the papers and discuss them in connection to theory. In chapter 9 I summarize key findings and give recommendation for further research.

1.2 SUMMARY AND STATUS OF ARTICLES

The papers in my thesis all describe energy use in the transport sector and related GHG emissions, but each paper has a different focus. It should also be noted that the papers were developed during the process of conducting research for this thesis. My first paper is about CO_2 emissions of exported goods from China. In the second paper, we are concerned with passenger transport and how there might be a trade-off between energy use and GHG emissions. In the third paper, we performed a literature review about rebound effects in the transport sector. In the last two papers we studied what affects energy use in freight transport. Through the five papers, I attempt to develop an understanding of transfer effects in the transport sector.

Title: CO_2-emissions from the transport of China's exported goods

Authors: Otto Andersen, Stefan Gössling, Morten Simonsen, Hans Jakob Walnum, Paul Peeters and Cordula Neiberger

Status: Published *Energy Policy* 38.10 (2010): 5790-5798.

This paper addresses carbon leakage by looking at freight transport in a globalized world and the geographical transfer of CO_2 emissions and the role of transport. To define workable system boundaries, this article is limited to the transport of exported goods between China and the receiving countries. China was used as an example because it saw an increase in the amount of freight transport as production moved from Western countries to Asia. For the first time, a comprehensive estimate of the "real" CO_2 emissions associated with the transport of China's freight was performed, using a life cycle analysis to calculate the emissions. The results suggested that in order to understand the importance of transports, the entire life cycle of transport systems should be considered and that their contribution to global emissions of GHG should be assessed on the basis of a consumer perspective. This is likely to reveal considerable underreporting in national GHG inventories in industrialized countries, and indicates the need for a better understanding and recognition of emissions associated with the various life cycle stages of transport. The paper addresses geographical transfer of CO_2 emissions and the role of transport.

Title: Energy Chain Analysis of Passenger Car Transport

Authors: Morten Simonsen and Hans Jakob Walnum

Status: Published in *Energies* 4.2 (2011): 324-351.

This paper investigates what is meant by trade-off effects between energy and GHG-emissions, using a life cycle perspective. Different fuels and drive train systems for passenger cars are compared to see whether some fuels and drive trains mitigate both climatic gas emissions and energy use. Except for the case of electric cars, where hydropower is the only energy source in the Norwegian context, no single car type scores favorably on both energy consumption and GHG emissions. This paper provides a foundation for understanding energy use and GHG emissions associated with a life cycle analysis of transport systems. The paper gives a foundation to investigate what is meant with trade-off effects.

Title: Rebound effects: The missing link in explaining why Sustainable Mobility has not been achieved?

Authors: Hans Jakob Walnum, Carlo Aall and Søren Løkke

Status: Published in *Sustainability* 6.12 (2014): 9510-9537.

This paper looks at whether rebound effects are the missing link in explaining why sustainable mobility has not been achieved. The paper addressed rebound mechanisms and illustrated different positions found within the scientific rebound discourse with examples from previous research about rebound effects and transport. It was the first comprehensive theoretical and literature review about the connection between rebound effects and sustainable mobility. We found it valuable to study rebound effects from the lenses of several disciplines and perspectives, since rebound mechanisms are better understood and revealed than by than by a single disciplinary approach.

Title: Does driving behavior matter? An analysis of fuel consumption data from Heavy Duty Trucks

Authors: Hans Jakob Walnum and Morten Simonsen

Status: Published in *Transportation research part D: transport and environment* 36 (2015): 107-120.

This paper looks at the determinants of fuel consumption in real-world traffic situations using a set of driving indicators: load weight, trailer type, route, automatic gear-shift use, cruise control use, use of more than 90% of maximum torque, a dummy variable for seasonal variation, time of day running idle, driving in highest gear, and rolling without engine load. We found in our specific case and analyses that the variables associated with infrastructure and terrain have effects that are 10–12 times higher than the effects of variables that we attributed mainly to driving behavior. Still the model show that driving behavior matter. We also found that vehicle procurement matters and will be important to lowering fuel consumption. In other words, this paper investigates what influences energy use at the micro level for freight transport.

Title: Driver and response model for Norwegian road freight transport in the period 1993-2013

Authors: Hans Jakob Walnum and John Hille

Status: Published in the report series of the Western Norway Research Institute (WNRI). *WNRI report* nr. 5 (2015). (Not peer-reviewed).

This paper looks at what affects energy use at the macro level for freight transport. The study developed a theoretical model of the growth in road-freight transport in Norway by identifying the likely drivers of such growth and to explore how they have contributed to the growth in energy use. Some of the drivers strongly accentuated this growth, while others have mitigated it. An in-depth study on both the indirect and direct drivers behind energy use in freight transport in a Norwegian setting had not been done previously. We also considered whether there was a shift of freight from sea and rail to road and evaluated the potential for increasing sea and rail transport of goods now transported by road. We found a close link between GDP and freight transport growth in the period 1993–2013. As such, it seems to be unrealistic in the short run to reduce the demand for freight transport in a Norwegian setting as long as the economy keeps growing. During the period under investigation there were no sign of moving goods from road towards sea and railway in Norway; rather, development during the period has gone in the opposite direction.

2. HOW TO ANALYZE AND UNDERSTAND TRANSPORT SYSTEMS?

There are many ways to analyze and understand transport systems. I have chosen to look at the transport system as a complex system. I will argue that transport systems should be analyzed through interdisciplinary research with a focus on underlying drivers for transport growth.

In the period 1990–2012, the trend in Norway was a steep increase in both person kilometers and tonne-kilometers. Traffic growth has increased from 53.881 million passenger-km to 75.186 million passenger kilometers for domestic passenger traffic, and from 26.589 million tonne-kilometers to 63.252 million tonne-kilometers for domestic goods transport (Statistics Norway, 2015). However, the most extreme growth rate is connected to travel abroad by air which rose by a factor 5 in the period 1990-2012, and corresponds now to about 2/3 of domestic passenger kilometers with private cars in Norway (Hille, 2013). During the same period there has been an improvement in both fuel efficiency and in the reduction of local emissions, by phasing in more fuel-efficient cars and by implementing Euro standards that have reduced emissions on a per unit scale such as per km. Nevertheless, traffic growth has resulted in an increase in total energy use and in GHG emissions (Holden, 2012). The reasons for the growth in traffic are complex and related to modern society and everyday life (Urry, 2007). Reaching the goal of 60-80 percent emission reductions in GHG will require a broad understanding of the mobility system and the drivers behind traffic growth for both passenger and freight transport (Vogel, 2015).

Since I study transfer effects within the transport sector, I am interested in finding out why there has been an increase in transport? I am also interested in how we can understand and analyze transport and mobility, since the entire mobility system needs to be considered to develop strategies and policy measures (Vogel, 2015).

There is a difference between transport and mobility; according to Givoni and Banister (2013) mobility, as understood within transport research, covers the movement of both people and freight and is related to the total amount of travels undertaken on all forms of transport. It can be considered to be situated between the demand for transport and the infrastructure that allows this demand to be realized. They state that transport goes beyond this definition and includes the modes of transport as well as the supply of transport from various institutions and organizations. Recently, the concept of mobilities has also entered the discourse (Urry, 2007). Mobilities refers to several mobility concepts and includes:

> "the large-scale movements of people, objects, capital, and information across the world, as well as the more local processes of daily transportation, movement through public space and the travel of material things within everyday life" (Hannam et al., 2006 p.1).

Thus the concept of mobilities are concerned with several mobility systems and also the inter-relations between them. I am in the thesis concerned with why mobility as understood within transport has kept raising. I interpret mobilities to highlight that larger societal conditions and reasons should be sought for why people travel and why materials are on their move (Urry, 2007).

Cresswell (2006) have pointed out that to understand mobility we must go beyond the simple transport of people from point A to point B. Mobility practices depends on numerous sociological, cultural, political, and economic processes (Givoni and Banister, 2013). One theoritical position that have dealt with the complexities connected to transport and mobility is sociotechnical transition theory. MacMillen (2013a) points to that the various mobility systems could be interpreted as regimes (MacMillen, 2013a). Smith et al. (2005 p.1493) shows to the established literature (Geels, 2002a, b; Rip and Kemp, 1998) and find that:

" the term 'regime' is used as a short-hand for a series of complex, nested real world phenomena, embodying natural and artificial physical elements, as well as social, economic, cultural and cognitive attributes. Regimes exist across different empirical scales".

However, such a complex system makes it difficult to make holistic policies and changes. Solutions to environmental problems connected to mobility issues seem to favor `end-of-pipe policy` that do not aim for systemic changes. Current transport policy has rather a prioritization for solutions that address symptoms and effects through fuel and engine efficiency advances instead of policies aiming for the underlying causes of emission growth in the transport sector. Anable and Shaw (2007) did an analysis of the UK transport sector where they found that transport and climate policies are misaligned in terms of addressing the carbon emissions in the transport sector. They address that policies should move beyond the focus on technological fixes.

I strongly agree that the transport sector and the various transport systems, which I address in this thesis, are complex systems that need a transition to accomplish fundamental reductions in energy use and related GHG emissions. However, I will not go into a detailed theoretical discussion on socio-technological changes nor transition theories, since my main emphasis is to explain the role that transfer effects play in transport. My main approach in this thesis is one of non reductionism and interdisciplinarity (Danermark, 2002), perspectives which will be outlined in detail in chapter 4. As such, transport associated transfer effects cannot solely be explained through theories and concepts belonging to one single discipline. Non reductionism implies to take an interdisciplinary stand to understand complex problems. Knowledge from various disciplines needs to be integrated to understand the phenomenon under investigation (Høyer and Næss, 2008). I will also look at some important causal mechanisms. What are the relevant structure, agencies and mechanisms that could explain transfer effects? At least four main disciplines and perspectives will help to provide an understanding of the complexity associated with transport growth (Danish Road Directorat, 2000): 1. an *economic framework*, 2. a *sociological framework*, 3. a *political-institutional framework*, as well as 4. a *spatial-planning framework*. I emphasize that various explanatory frameworks behind traffic growth do not contradict each other and should be understood in relation to each other.

1. *In the economic framework* is the viewpoint that transport is a commoidity where the correlation between economic activity and traffic volume is emphazized. Demand for transport depends on level of economic activiety which also is well documented (Dargay and Gately, 1999; Schafer and Victor, 1997). According to this framework cost of transport has an influence on traffic growth and increased cost could be used to reduce the demand for transport. Attention is given to implementation of economic instruments for transport (car price, gasoline, and vehicle taxes). Travel speed has also been emphasized because increased travel time reduces the time used for transport. Time for travelling is seen as a `cost` since each minute of travelling could have been used productively in other types of activities. The quest for reducing travel time by increasing speed reduces the cost of transport. As such, the cost for transport goes down which lead to traffic growth (Danish Road Directorat, 2000).

2. The *sociological framework* believes that transport demand should be understood in terms of the relationship between the individuals and the social conditions they live under. This perspective emphasizes the importance of looking at the social and psychological causes for transport demand. There needs to be a better understanding of society's expectations related to mobility. This applies to the following:

A. Organization of everyday life—how the car is used to get to daily activities is in turn related to the location of housing, schools and day care centers, and employment and shopping opportunities.

B. Leisure transports—a higher demand for mobility is seen during leisure time, especially related to international leisure (and also business travels). Urry (2012) explain this by the close connection between mobility and social status connected for example to flying long distances to abroad. There is thus a close connection between cultural practices and social norms, in which technology, knowledge structures and emotions are involved (Sheller and Urry, 2006). Car and aircraft have in particular produced lifestyles, relations, communities, work and recreation patterns that represent socialization into specific norms and habits of mobility consumption (Frändberg, 2008; Lassen, 2006; Schwanen et al., 2012).

3. The political-institutional framework looks at the interests underlying the desire for economic growth and mobility. It focuses, for example, on how policy and the political system impact infrastructure development and public transportation as well as taxes and subsidies in the transport sector. Business interests have also helped generate growth in mobility, both nationally and internationally. International agreements are also a significant example; EU has, through the internal market, contributed to increased traffic. There is considerable influence of automobile and aviation organizations on the design of policies, which has hampered more strict legalisation for instance with regard to taxation, speed limits, and congestion charges(Gössling and Cohen, 2014).

Gössling and Cohen (2014) found that an `implementation gap` exists associated with transport policies. Policies could be interpreted to be in line with ecological modernization principles based on technological optimism, the belief in market based mechanisms and that voluntarily behavioral change will solve problems associated with GHG emissions. However, they argue that this will lead to `path dependency` and social-lock in action and thus will not curb transport volume and related GHG emissions.

4. The *spatial-planning framework* underline the role that infrastructure provision and residential location plays on traffic growth. This perspective includes the physical planning of infrastructure development with respect to its traffic demand. Land use development, including the location of housing, schools and day care centers, employment and shopping opportunities (which also are part of the sociological approach), is also included. The focus on travel-time savings and the value of time is closely related to the notion of consumerism and materialism, where more and faster are assumed to be better. According to Givoni and Banister (2013), investment in transport infrastructure to support economic growth and reduce congestion is still dominant in transport planning.

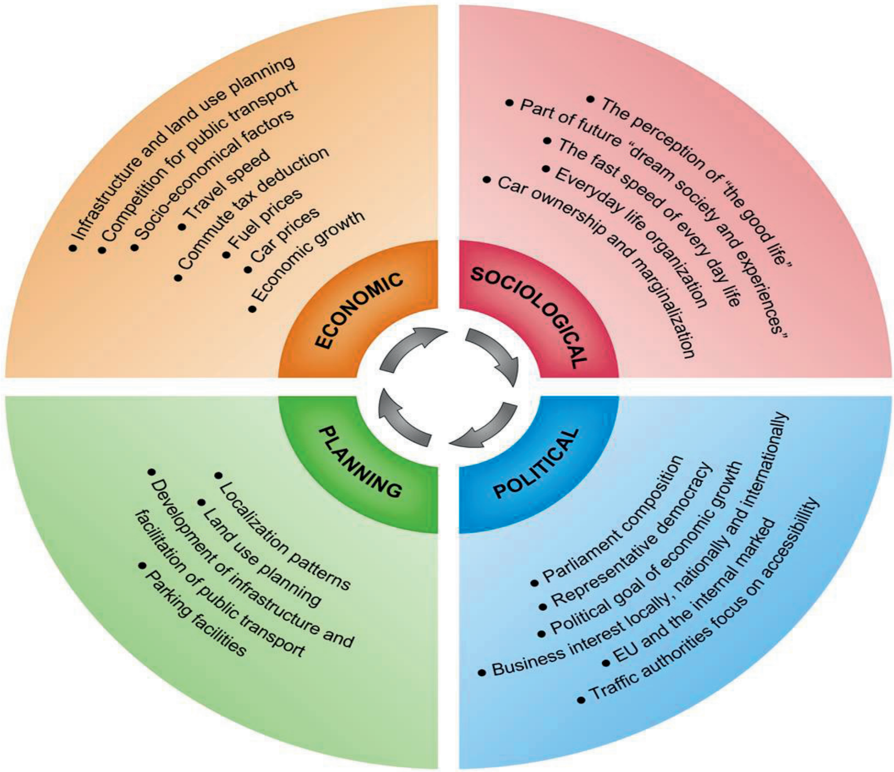

Figure 1 "The transport growth wheel". Why do transport volumes and emissions grow? Inspired by perspectives and variables obtained from a report by the Danish road directorat (2000).

Figure 1 summarize the four positions of transport growth, however they had a main emphasis on growth in passenger transport. Although some of the causes of freight transport growth are largely congruent with the causes of passenger growth, they are less understood and documented. Moving freight is highly complex and quite different from moving people; for example, the cost structure of the two is different. The energy cost of driving is only part of the cost for freight transport; labor and capital cost must also be included (De Borger and Mulalic, 2012; Matos and Silva, 2011; Winebrake et al., 2012). The lack of policies related to the freight transport sector could be associated with its complexity and its close link to economic growth (Piecyk, 2010). The sector includes many actors: haulers, shippers, and governments, as well as producers and consumers that rely on freight transportation. It is not entirely clear who should bear the responsibility, and there is little coordination between actors. General economic activity as measured by GDP has shown a clear correlation with growth in freight transport. The link between freight transport and GDP can be explained by an increased consumption of material resources (raw materials) and in the produced commodities. In addition, changes in the global production structures have meant that each ton of final product is being transported more frequently in the value chain and the transport distance has increased. Relative transportation costs have also gone down. Developments in energy efficiency have occurred at a slower pace than for passenger traffic. It has long been a policy objective to transfer freight from road to sea and rail, but this has not been done satisfactorily because of barriers related to prices, flexibility, and structure (Piecyk, 2010).

On the background that freight transport was an under researched area we developed a model inspired by the OECD pressure-state-response environmental indicator model in paper 5. This logic has also been applied in a number of sustainability indicator systems (Aall and Norland, 2005). This could be understood as a supplementary perspective to the four disciplinary perspectives outlined above to understand causes for growth in transport.

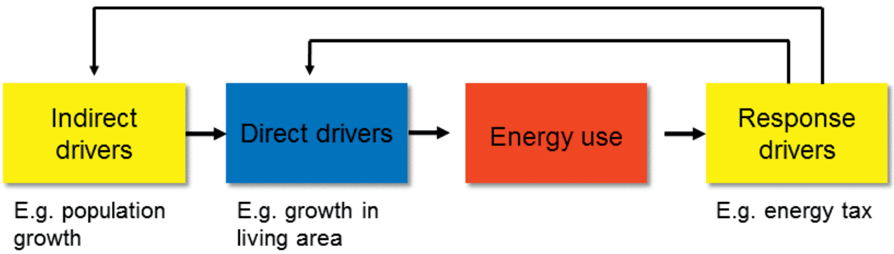

Figure 2 Simplified driver presure state response model adopted from Hille et al. (2011).

Figure 2 addresses problem generation and manifestation as well as attempts to solve problems. Much of the increase in environmental pressure from the transport sector can be explained by a pronounced increase in the volume of freight and person transport. This increase in volume has, in many cases, outweighed any benefits derived from both an increase in energy efficiency and a shift toward more environmental modes of transportation (Walnum et al., 2014). The scheme could be applied to both passenger and freight transport. Direct drivers are physical entities connected to freight transportation that directly governs the amount of GHG emissions and transport costs (e.g., transport distance, type, volume and weight of goods transported; transport mode; technical characteristics of vehicles, trains, and boats; and type of fuel). Indirect drivers are societal factors (e.g., economic growth, import-export restrictions, transport infrastructure, energy prices, and labor costs). Response drivers are policies that may interfere with either direct drivers (e.g., fuel taxes and regulation of transport technologies) or indirect drivers (e.g., toll regulations and road pricing). Both the interdisciplinary perspectives and simplified driver pressure state model are off course simplifications of how we could understand and analyze transport systems, however they give a valuable insight since they not merely focus on the direct emissions from transport, but look at underlying mechanisms and causes for transport growth. As such, they also give an input to understand underlying mechanisms of transport associated transfer effects.

From this chapter I have learned that current transport systems are not sustainable (Holden et al., 2013; Høyer, 1999). They are complex system and there are many causes for growth in transport. It is likely that no change will happen without a substantial change in government policy, since transport systems then will continue be unsustainable (Holden, 2012). In the next chapter I will look closer into the discourse on how to achieve sustainable mobility, which is derived from the larger discourse on sustainable development. The purpose is to try to understand the implication of making the transport system more in line with sustainability and also taking into account various transfer effects.

3. SUSTAINABLE MOBILITY

Using sustainable mobility as the point of departure provides the following:

- A foundation for analyzing transport systems and strategies for achieving sustainable mobility.
- A framework and point of departure for reviewing different positions within the environmental discourse, and how these positions approach the goal of sustainable mobility
- A framework for discussing different strategies and how different positions within the environmental discourse relate to achieving sustainable mobility.

Most importantly, I will discuss how the different positions and strategies relate to transfer effects.

Understanding what sustainable mobility involves requires looking at the concept from which it is derived—sustainable development. Sustainable development has been called the dominant ecological discourse of recent times (Dryzek, 2013), since the publication of Our Common Future, in 1987 by the World Commission on Environment and Development (WCED). It marked a renewed interest in environmental issues—the so-called second wave of environmentalism (Røpke, 2005). The debate is still ongoing, with profound discussion about the term's content (Assadourian and Prugh, 2013).

Despite diverse interpretations of the concept of sustainable development in the policy and scientific discourse, the most frequently cited definition is from Our Common Future. This definition states that sustainable development should: "meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED, 1987 p.43). It contains two key concepts: the concept of `needs`, in particular, the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by technology and social organization on the environment's ability to meet present and future needs (WCED, 1987). Thus, an element of distributive justice over time and across geographical spaces is involved in the concept of sustainable development, but with a priority to meet the needs of the poor (Lafferty and Langhelle, 1999). The conceptual boundaries of sustainable development are not strictly determined, which could reflect the different interests included in the authorship of the WCED report; the different viewpoints have allowed for different interpretations of the term (Daly, 1996; Høyer, 1999). Several other definitions, which are somewhat contradictory, are also found in Our common future for example:

> "In essence, sustainable development is a process of change in which the exploitation of resources are, the direction of investments, the orientation of technological development, and institutional change are all in harmony with each other and enhance both current and future potential to meet human needs and aspirations." (WCED, 1987 p.46).

Historically, there has never been one specific interpretation of sustainable development that has had general support. In an attempt to address the difficulties involved in defining and interpreting sustainable development, Høyer (1999) tried to arrive at a kind of lowest common denominator—some core characteristics—that can be used as a guideline to describe more clearly the differences between the various definitions and perceptions of what sustainable development "is" or "should be". His main point was that even if there are many and partly contradictory definitions of a concept, it should be possible to arrive at some joint agreement of the term's characteristics.

Høyer (1999) distinguishes between extra prima, prima, and secondary characteristics (terms borrowed from thermodynamics) of sustainable development. In line with a social science understanding of concepts, he allows for a somewhat looser meaning than that found in the natural sciences, requiring only that core aspects and dimensions are present. According to Høyer (1999), sustainable development could be considered at the same level as democracy, liberty, and welfare, implying that it must be based on certain values and norms. However, because sustainability originates from natural science, it must also consider nature's values and norms. This also suggests that the concept requires an interdisciplinary approach. As a result, sustainable development as a concept and as a political goal can have three "roots"—1. natural science, 2. social sciences and humanities, and 3. legal theories and theories about human needs. The sustainability part can be linked to (natural) science (originally forestry where the goal was to secure a sustainable use of the forest (Von Carlowitz and von Rohr, 1732), while the development part originates in legal theories and theories about human needs.

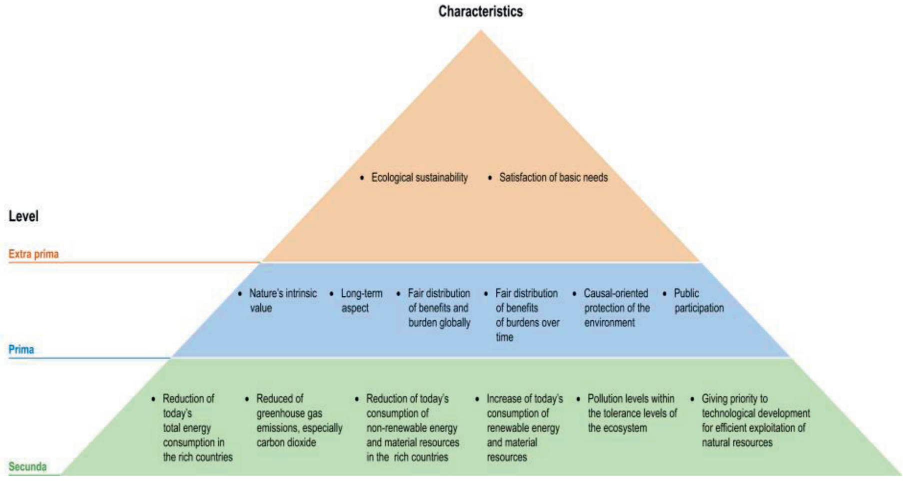

Figure 3 Characterstica of sustainable development based on Høyer (1999)

Figure 3 shows the ranking of the characteristics, and that extra prima characteristics are most in line with sustainable development. Høyer (1999) emphasized that not every policy that aims to reduce emissions is necessarily in line with sustainable development, which should be in line with ecological sustainability. Fair distribution is also needed, globally and over time, as well as prioritizing the satisfaction of basic needs. Secondary characteristics must be derived from extra prima and prima characteristics.

Our Common Future argued for the importance of energy use in financially rich parts of the world to allow for the growth of developing countries. In the low energy scenario of the report it is recommends that wealthy countries reduce their levels of energy consumption by at least 50% within 40 to 50 years, with 1980 as the base year. In addition, Our Common Future argued for fundamental political and institutional changes that would change the way we handle environmental issues and problems along low energy paths. Such changes would encompass a change in approach from a `standard agenda` to a `source-oriented` approach. The standard agenda has a main emphasis on environmental effects and their impacts. The source-oriented approach concentrates on the source of these effects or the underlying causes, including the political causes. The latter strategy looks at solutions in a much broader sense, and points to the need for more fundamental changes in society. The `source-oriented approach` says that technological solutions are not sufficient, since they only solve symptoms and do not address the causes of environmental problems. New symptoms will come into being as long as the causes for environmental problems are not solved. Solutions within the standard agenda will often transfer environmental problems, from one sector to another sector, for example, and create other serious environmental problems (WCED, 1987).

Our Common Future argued that continuous economic growth of 3% to 4% per annum for industrial countries could be environmentally sustainable as long as the content of economic growth changes in line with the resource foundation, for the reason to allow financially poor countries to grow out of poverty by international trade (WCED, 1987). Economic growth that leads to increased use of resources and increased pollutions, in the financially rich part of the world could not continue. This implied, according to Our Common Future, that economic growth that produces the same per unit of emissions per GDP should not continue. However this has been criticized because the commission did not highlight potential transfer effects that under prevailing conditions, such as liberalized trade and conventional efficiency gains, might actually work against sustainability (Wackernagel and Rees, 1996). Others criticized the belief in economic growth combined with a reduction in energy use and related GHG emissions. Daly (1996) sees sustainable growth as a nonsensical self-contradiction. Furthermore, he makes a clear distinction between growth and development: Development is a qualitative improvement that allows for stock maintenance per unit of throughput and more service per unit of stock. Daly (ibid.) believes that de-coupling between growth in the economy along with a reduction in energy use, resources, and GHG emissions is impossible to achieve, and therefore rejects the notion of continued economic growth.

The link between the environment and the economy can be interpreted in different ways. One interpretation can be found in the definitions of strong and weak sustainability. Weak sustainability is based on the neoclassical belief that human-made capital can be substituted for depleted natural capital. For example, factory income could substitute for income from a forest. Strong sustainability, on the other hand, also addresses the intrinsic value of nature; in addition to wood fibers, a forest can provide flood and erosion control, heat distribution, climate regulation, and a variety of other non-market functions and values that are necessary for ecologically sustainable development (Wackernagel and Rees, 1996). Although these examples are of non-market functions of nature that are instrumental for human purposes, the intrinsic value of nature goes beyond even this (Arler et al., 2015).

A discourse which is related to the discourse about strong and weak sustainability is found in the differences between environmental economics and ecological economics. Environmental economics is a sub-discipline of economics concerning environmental issues and analyzing environmental problems within a neo-classical framework. This position views environmental problems as externalities caused by market failure; i.e., choices of some people affect other people, but market prices currently does not take into account the environmental costs. The failure of markets in efficiency to reflect the true cost of environmental goods has caused the current ecological crisis. Hence, the cost should be equal to the value of the damages and should be solved according to the principle of the “polluter pays”, by internalization of externalities. According to this position, certain natural resources can be used up because the price will rise when it becomes scarce and substitutes will be found through technological progress. In this position, it is common to deny any general scarcity or ultimate limits and to also rely on technological fixes. The policy strategies actually used include `Pigovian tax` (i.e., a tax levied on polluting agents that is equal to the amount of incurred social damage) and tradable pollution permits. The goal of these economic instruments is to change behaviors of consumers and producers to become environmental benign. The position assumes that environmental problems are part of overall economic issues, and thereby can be analyzed and solved in the neo-classical economic system (Xue, 2012).

On the other hand, ecological economists look at the economy as an open subsystem of the Earth's ecosphere, a position that calls for the awareness of human-dependency on well-functioning ecosystems that provide the basic life support for human societies. It recognizes the limits to the material growth of the economy. The human economy is embedded in nature; secondly, they emphasize that the economic process can also been seen as a natural process with respect to biological, physical, and chemical processes. Society should be seen as an organism within a social metabolism. This position is critical of the idea of substitution between natural and man-made capital, and of the effect that economic growth has on the environment (Røpke, 2005).

Strategies to achieve sustainable development within transport or how to achieve sustainable mobility were not explicitly mentioned in Our Common Future. In a 1992 "Green Paper" the Commission of the European Union launched the concept of *sustainable mobility* (EUCOM, 1992). Sustainable mobility evoked considerable interest, both in politics and science. In his thesis, "Sustainable Mobility - the Concept and its Implications", Høyer (1999) discussed the relationship between the major charcteristica of sustainbale development and their relation to mobility. This was further developed by Holden (2012 p.61-64) who translated Høyers characteristica into a mobility setting:

1. Impacts of transport activities must not threaten long-term ecological sustainability.
2. Basic mobility needs to be satisfied and entails the accessibility to appropriate means of transport to meet basic human needs, such as travel to work and to other vital private and public services. Thus, basic mobility needs are not goals in themselves, but rather necessary means to accomplish the goal of meeting basic human needs.
3. Inter- and intra-generational mobility equity should be promoted. Everyone should have access to a specified minimum level of mobility in the present as well as in the future. Mobility equity does not necessarily mean equity in mobility outcome.

According to Høyer (1999 p.187), environmental problems from transportation could be solved by different measures. In his thesis he identified the following measures:

1. Reductions in mobility
2. Reductions in infrastructure provision
3. Transfer between different modes and means of transport
4. Increased load factor
5. Use of alternative energy sources
6. Increased energy efficiency
7. Purification of polluting emissions

The higher we go in the ranking from 1 to 7, the closer we are to the core of the sustainable mobility concept; measures that aim for reduction in mobility corresponds most strongly to sustainable mobility. In a later publication, Holden et al. (2013) found that sustainable mobility implied that the maximum threshold value for daily per capita energy consumption for passenger transport was 5.6 kWh and that the minimum threshold value for daily per capita travel distance by motorized transport was 9.2 km. Currently, energy use for person transportation in the EU is a factor of 3–5 above that maximum threshold (Holden et al., 2013) and is, of course, highly dependent on the system boundaries. In addition to direct energy use, indirect energy use and related GHG emissions could be included into the calculations for the propulsion of vehicles, i.e., the energy required for the construction of infrastructure and for the manufacture of vehicles as well as for the provision of fuel.

3.1 STRATEGIES FOR SUSTAINABLE MOBILITY

Høyer (1999) discuss three main strategies for reducing emissions from transport and for obtaining sustainable mobility—*efficiency*, *substitution*, and *volume reduction*—I have chosen to categorize the three different strategies for achieving sustainable mobility because each has a broad scope of associated policy instruments. In addition to these three categories lies a possibility for business as usual or `no change`, so that actions will not systematically seek to reduce energy use and GHG emissions from transport. In Our Common Future, the efficiency and substitution strategy were promoted, and reduction had a more limited role.

A key question is how much technology can help in achieving sustainable mobility, and how much will depend on travelling less and relying on the most efficient forms of transport (Givoni, 2013)? The idea behind the efficiency strategy is that we need to develop technological solutions that involve more efficient transportation options in terms of resource extraction, fuel consumption, and emissions. This strategy can be sub-divided into two separate ones. In the first are those that will enhance existing technology. A number of studies show that, at least in theory, there is a large potential for reduction of emissions and energy use. The other main technological orientation focuses on alternative engine technologies and fuels. Efficiency is the preferred strategy for reducing GHG emissions and energy use. It implies that reducing environmental impact is associated with each good or service. The success of this strategy depends on the absence of large rebound effects. However, most OECD countries pay little attention to such possibilities and offer few options for mitigating undesirable consequences (Sorrell, 2010).

The *substitution strategy* is directed at transport patterns. The key point is how journeys take place and not how many, and in practice, how the journeys are distributed between different modes of transport. This strategy includes the switch from cars to rails, trams, and buses for passenger transport and the switch from trucks to rails and sea transport for freight transport.

The first two approaches do not question the volume of travel. We can travel as much as before, perhaps even more; but we have to travel in an environmentally benign way.

The *volume or reduction strategy* denies that a focus on technology and the composition of our travels is sufficient. In addition to traveling more efficiently and developing new transport patterns, we simply must reduce the amount of kilometers traveled.

The scientific and policy discourse on sustainable mobility has, in some cases, stated that these three strategies are independent of each other and that all three will lead to a reduction in GHG emissions and energy use. However, theories on transfer effects point to possible inherent influences between the three strategies (Holden, 2012; Holden et al., 2013) and opinions differ on which ones are best suited for achieving sustainable mobility. However, other classifications are also possible such as mentioned by Givoni (2013) where he outlines three routes to achieve low carbon mobilty. Here he distinguish between a pathway consting of `technologcal fix`, identical to the efficiency strategy. He also mentioned `glocalization` i.e. to move production which implies production in self-contained local or regional markets. I find his last pathway `rethinking economic growth` very intersting. I interpret it as a supplement to the volume reduction strategy mentioned by Høyer (1999). Høyer (1999) did not explicitly discuss economic growth in connection to the volume reduction strategy. It is well-known that higher incomes are associated with higher levels of car ownership and usage (Dargay and Gately, 1999). A World Bank study (Timilsina and Shrestha, 2009) found that that savings from fuel switching, mode shifting, and changes in emission coefficients were eclipsed by an overwhelming growth in the economy and population. Freight transport volumes grow with GDP (decoupling is not seen) and passenger and freight transport volumes increase with economic growth. Central to the scientific and political discourse is whether environmental sustainability and sustainable mobility can be achieved through technological improvements and changes in consumption patterns, or whether the total volume of consumption must be limited and include a reorientation away from the goal of continuous economic growth.

To simplify, the three strategies to achieve sustainable mobility can be linked to a wider disagreement in the environmental discourse: Curbing energy use and GHG emissions through the *efficiency strategy* (1) and *substitution strategy* (2) can be translated into `changing the growth of transport volume`. *Volume reduction* (3) also highlights the need for `less transport`. *Efficiency* and *substitution* are more in line with ecological modernization, and the *volume reduction* strategy are in line with a degrowth position.

I have chosen to look closer at ecological modernisation and degrowth since they go beyond the discourse on economic environment interactions (which are the primary discourse and disagreement connected to weak vs. strong sustainability and environmental vs. ecological economics). Ecological modernization and degrowth discuss policy and social science perspectives in addition to economic and environmental interactions. In the next chapter I will discuss how ecological modernization and degrowth look at solutions for environmental problems in the transport sector, as well as the two positions viewpoint on transfer effects.

3.2 ECOLOGICAL MODERNIZATION

The roots of the ecological modernisation positions are found in the 1980s in an era of neoliberalist globalization, the “new economy,” and of “win-win” environmental policies (Mol et al., 2009). One important strategy, which was coined “eco-efficiency” in 1992 by the World Business Council for Sustainable Development (WBCSD, 1992), originates from a more general idea of how society could be transformed in order to solve environmental problems (Spaargaren et al., 2000).

Some have seen ecological modernization to be the dominant paradigm within those environmental policies in which environmental harms are minimized through technological progress and economic growth (Givoni, 2013; MacMillen, 2013b). Ecological modernization has also gained momentum as a strategy for solving environmental problems within the transport sector (Givoni, 2013). Examples of how this strategy is promoted include electrifying the transport sector, introducing alternative fuels, and ecodriving. The focus has mostly been on technological improvements that reduce the energy consumption of the vehicles rather than reducing the transport demand in the long run. Although this approach is likely to reduce energy use or the emission level per unit, overall traffic demand is not reduced since transport becomes both efficient and affordable (Vogel, 2015). Technological solutions alone will not cause a transition towards low carbon mobility societies, the whole mobility system needs to be taken into account, since economic growth tends to neutralize environmental improvements if increases in eco-efficiency remain incremental (Jänicke, 2008).

However, others believe that it is the failure with inclusion of policy in line with ecological modernization which is the real problem. We have not succeeded in decoupling energy consumption from economic growth because we have not made enough effort: Energy and carbon prices are relatively low and policies that encourage energy efficiency are not well enough founded or implemented. To decouple energy use and GHG emissions from economic growth, we should introduce more effective regulatory standards, financial support, and pricing of carbon emissions (Sorrell, 2010). Further problems are associated with "Modernization losers" who are often powerful enough to limit the scope and effects of environmental policy and present a challenge for ecological modernization. They may not be strong enough to prevent environmental innovations and knowledge-based policies, but when it comes to policy implementation, power-based resistance remains an important obstacle (Jänicke, 2008).

Some have seen sustainable development as a synonym for ecological modernization; that is, with the similarity that economic growth can continue if the right technological solutions are found and implemented (Dryzek, 2013). Langhelle (2000) has pointed out that sustainable development cannot be understood within an ecological modernization framework because concern for global environmental and development problems, social justice and global ecological interdependence differs between ecological modernization and sustainable development.

According to Mol and Janicke (2009), the ecological modernization discourse has become much more nuanced. In the 1980s, thinkers held a more or less uncritical belief in models that would automatically lead to greening of production and consumption; they ignored political struggles between interest groups and issues of ethics and moral values. In the early years, this position was characterised with technological optimism; whereas in recent years, the ecological modernization discourse addresses the influence of structures. Jänicke (2008) argues for the development of an "ecological structural policy" that imposes non-technical solutions that change the structure of supply and demand. This does not only affect the structure of industry but also individual life-styles (e.g., personal mobility and housing). Structural solutions deeply affect established interests and behavioral structures and cannot rely on the traditional ecological modernization approach. Existing problems cannot be solved through marketable technological innovations alone.

Ecological modernization has to some degree addressed that the introduction of environmentally benign technology can increase resource productivity. However, the strategy has a focus on material intensity (efficient use of materials) and energy intensity (efficient logistics). The key and basic assumption of ecological modernization is the idea of environmental re-adaptation of economic growth and industrial development by means of increasing the marginal environmental efficiency of industrial production measured, for example in the form of energy per unit of production or per unit price. The final and total output received less attention; that is, whether applying a strategy of ecological modernization or eco-efficiency has actually reduced the total environmental pressure on society, or just literally moved the pressure to other regions or related economic activities, often referred to as geographical transfer effect and rebound effects (Aall and Husabø, 2010; Walnum et al., 2014) .

3.3 DEGROWTH

Several definitions have been applied to the concept of degrowth; for example, Schneider et al. (2010 p. 511) defined degrowth as: "an equitable downscaling of production and consumption that increases human well-being and enhances ecological conditions".

A second definition simply uses one word: "Different."(D'alisa et al., 2014 p. 4)

In a magazine article in Le Monde diplomatique Latouche (2004) wrote that degrowth could not be understood as a concept:

> "We are sorry to disappoint the media, but degrowth is not a concept. There is no theory of contraction equivalent to the growth theories of economics. Degrowth is just a term created by radical critics of growth theory to free everybody from the economic correctness that prevents us from proposing alternative projects for post-development politics. In fact degrowth is not a concrete project but a keyword."

Degrowth is not just a quantitative issue of a shrinking economy. More fundamentally, it is about a paradigmatic re-ordering of values and, in particular, the affirmation of social and ecological values and a re-politicization of the economy (D'alisa et al., 2014). Most works on degrowth link it to sustainability, using the concept of "sustainable degrowth." This thinking is consistent with the original works of Georgescu-Roegen, who has been considered to be a forefather of degrowth thinking, he emphasized the natural physical limits of growth, much similar to our later concept of ecological sustainability. The history of degrowth and the degrowth concept goes back to 1970s; Andre Groz was the first to use the French word "décroissance." This background launched the degrowth concept (Høyer, 2011).The first degrowth conference (Economic Degrowth for Ecological

Sustainability and Social Equity) was held in Paris in 2008. Proponents of degrowth argue that economic growth is not sustainable and that human progress without economic growth is possible.

Schneider et al. (2010) distinguish between unsustainable and sustainable degrowth; the latter is defined thus:

> "Sustainable degrowth may be defined as an equitable downscaling of production and consumption that increases human well-being and enhances ecological conditions at the local and global level, in the short and long term. This is a new movement, and a varied one. The degrowth proponents are far from unified; the movement unites supporters from different philosophical positions and political movements."

However, I believe that there are six common features of degrowth.

1) Degrowth challenges the reliance upon GDP as a useful measure. The goal is the pursuit of well-being, ecological sustainability, and social equity. Degrowth can allow socio-environmental improvements while GDP falls. GDP can go down but other dimensions of life can improve (Schneider et al., 2010). Instead of growth that requires increasing inputs (energy, raw materials), there is a more intelligent and equitable use of inputs (stable or decreasing) that improves the quality of life, as measured in Gross National Happiness (GNH). If use of inputs is capped, GDP may flatten, but an increase in GNH is still possible.

2) Degrowth challenges the belief that eco-efficiency can be a solution in its own right. Growth that comes from a more intelligent use of inputs, which achieves greater efficiency and sustainability, can eventually be cancelled out by increases in production and consumption. In growing economies, savings achieved by eco-efficient technologies are consumed elsewhere (Schneider et al., 2010). To put it another way, growth requires more and more efficiency in a sustainable society. An annual economic growth of 3.5%, if continued for 200 years, would require an increase in resource efficiency by a factor of 950 (Xue et al., 2012).

3) Degrowth challenges the belief in a link between more equity and economic growth. Researchers have found that economic growth seems to cause greater social inequity. According to Jackson (2011), one-fifth of the world's population earns just 2% of the income. In 2005, the average ecological footprint per person in high income countries was 6.4 times larger than that of low-income countries (Xue et al., 2012). Degrowth proponents want local and global redistribution. Degrowth should lead to a steady-state economy for the global North, leaving space for growth in the South (Schneider et al., 2010).

4) Degrowth believes that the global economy should be in line with the capacity of the eco-system. We can achieve reduction in consumption and solve the resultant environmental challenges, such as GHG emissions, through economic degrowth. Degrowth is needed to prevent the overloading of source and sink capacity. However, governments all over the world seek to stimulate economic growth, hoping and claiming that decoupling strategies can bring about more environmentally-friendly growth patterns. Growth policies still have a hegemonic status in public debates and politics (Xue et al., 2012).

5) Degrowth believes that necessary changes should be made through democratic means. Downscaling, i.e. the reduction of consumption and production, should be done in an equitable and democratic manner, through decentralizing and deepening democratic institutions and repoliticizing the economy. For example, overpopulation can be solved by bottom-up action that empowers women and gives them control of their reproductive rights (Schneider et al., 2010).

6) Degrowth proponents argue that economic growth is the fundamental mechanism causing actual or potential rebound effects, and that technological solutions alone are not sufficient to reach environmental sustainability or full decoupling without degrowing our economy (Nørgård, 2013; Schneider, 2008). In the current international rebound effect discourse, economic growth is considered a key to the understanding of rebound and transfer effects and their significance. The degrowth concept fundamentally rejects ecological modernization in the form of green growth—sustainable growth—as a real option of long-term sustainability.

Although ecological modernization has been called the dominant paradigm, transport research has seen an emerging interest in degrowth during recent years (Moriarty and Honnery, 2013). Some elements from degrowth, such as “rethinking economic growth” and limitations of GDP as an indicator for prosperity. have been mentioned in connection to transport research (Givoni and Banister, 2013). The degrowth position is concerned with insufficiency and potential transfer effects connected to technological fixes as well as with the negative consequences of an unlimited mobility ideal (Vogel, 2015). Key issues in the degrowth discourse is whether growth is a major driver for rebound effects, that growth could “backfire,” and how to avoid rebound effects. Inside transport is the key question whether reduction in energy use and GHG emissions are possible under conditions of economic growth.

Degrowth could be considered to mean “changing growth in itself.” We have not succeeded in curbing energy and related GHG emissions because (for example) potential energy savings have been offset by rebound effects (Van den Bergh, 2011). These effects result from deficient narratives and incompatible goals, and reduce the potential for energy savings and GHG emissions (Sorrell, 2010). Environmental policy initiatives tend to address only direct GHG emissions (mostly

CO_2) and ignore the connection to other impacts, such as energy and other life-cycle phases or how energy use and GHG emissions have been moved to other countries (Høyer, 2010).

Ecology has not been the sole priority. Sekulova and Schneider (2014) stated the following: If degrowth is promoted for "the sake of ecology alone, or equity alone, or democracy alone, or happiness alone, it could provide atrocious results".

Demaria et al. (2013) warned against resolving biophysical limits and environmental disasters without applying insights into the need to deepen and widen democracy; such an approach could result in eco-fascism. Also, resolving inequalities without paying attention to ecological limits could deteriorate environmental pressures further. A democracy without concern for justice and ecology could lead to further environmental damages.

A key weakness with the degrowth position is that it is unclear what degrowth implies in practical policy. How should the strategies promoted by degrowth get broad public support to make real political changes? How is it possible to get global engagement and involvement for voluntary and planned reduction of economic activities aimed at a better life? How could society organize into a degrowth society with re-oriented values, such as a radical reduction and sharing of working time, a re-focusing on reproductive activities, and providing basic income and upper limits for maximum incomes?

While the discourse on degrowth has influenced the academic world, there seems to be little acknowledgement of degrowth in practical policy. How should degrowth supporters organize and seek to influence public policies? A large number of citizens will have to support their arguments and see a path toward a degrowth policy with a re-orientation of values (Sælensminde, 2010).

3.4 COMPARIASON OF ECOLOGICAL MODERNIZATION AND DEGROWTH

Both positions agree on the following (Næss, 2010b):

1. Growth in the consumption of natural resources results in increased pressure on the natural environment
2. What we call environmental problems normally reflect real changes in the physical world, as distinct from how we talk about environmental problems.
3. The present level of consumption of key natural resources is already higher than what can physically be sustained in the long term. Present

levels of environmental pollution result in rapid degradation of ecosystems and conditions for human life.

Table 2 outlines the differences between the two positions in several areas, for example, the solutions to environmental problems.

Table 2 A compariason between ecological modernization and degrowth (inspired by Næss 2010b)

Challenges	**Position 1** **Ecological Modernization**	**Position 2** **Degrowth**
Solutions to environmental problems	Solutions can be found within the context of industrial capitalism. Capitalism must undergo a process of transformation to be sustainable in the long term	Institutional frameworks for changing from growth to degrowth are absent (e.g., legislation, regulations, taxation, and subsidies). Degrowth is needed to solve environmental problems.
View on the possibilities for decoupling and dematerialization	Decoupling of economic growth from resource consumption and environmental load (”dematerialization”) are key elements in this process of transformation.	Strongly opposes the idea that decoupling and dematerialization are sufficient. Not possible in the long run to compensate for growth in production and consumption by constantly reducing the environmental load per unit produced.
Why have mitigation policies failed?	Not enough effort. Transfer effects play a minor role.	Various systemic transfer effects limit the possibility for decoupling. Various transfer effects are a main reason for the failure of mitigation policies.
Transport	Tehnological fixes such as introduction of fuel efficiency standards, electrification of the transport sector.	Reduction in mobility, major reduction in GHG emissions and energy use could only be obtained by a degrowth of the economy.

From chapter 4 I have learned that there are differences in opnion on how sustainable mobility and sustainable development can be achieved and how to reduce energy use and GHG emissions in the transport sectors. Simplified, a polarization between two different `worldviews` of technological optimism and those claiming that a fundemental transformation of society are needed were found. In the next two chapters I will discuss my `worldview` or philosophical basis for research which have had a profound impact on research design, methology and interpretation of findings in the papers and the covering essay.

4. PHILOSOPHICAL BASIS FOR RESEARCH

In this part I reflect upon my metatheoretical viewpoint and how this has influenced my research. A metatheory could be defined as a: "set of presuppositions about the nature of the world and knowledge" (Bhaskar and Danermark, 2006 p. 295). Ontology, which refers to the objects of knowledge, differs from epistemology which refers to the condition of knowledge and covers theories of knowledge and knowledge production. This implies that ontology and the epistemological viewpoint are "guidelines" when we do science. Thus metatheory tells you what you can or cannot see and the kind of knowledge that can be acquired (Bhaskar and Danermark, 2006). The critical realism (CR) theory of science position is relevant as a metatheoretical approach for my thesis, because it emphasizes a non-reductionism standpoint and highlights a multilevel approach to explaining and understanding complex phenomena. As such, CR also highlights the need for an interdisciplinary approach to understanding complex phenomena.

Central to CR is its development as a theory of science critique of positivism, empirical ontology and causal explanations. It was meant to be a holistic and radical alternative to positivism, yet CR is also critical of the empty realism of social constructivism in which truth is reduced to discourses on the surface of reality (Danermark, 2002). By applying a CR approach, I mean that physical changes in time and space are real, not socially constructed; that is, they do not depend only on how we interpret and discuss changes in the environment.

> "How we construct, discuss and analyze environmental problems has all types of consequences. However, it must be based on the prerequisite that environmental problems also involve physical changes that will not disappear no matter how we construct, interpret, discuss or analyze them, and that they can only be avoided by making real changes in human-created structures and in our practices" (Høyer, 2002 p.120-121).

In CR, ontological questions cannot be reduced to matters of epistemology because questions about reality are not reduced solely to questions about our knowledge or to discourses about this reality. According to CR, ontological reality consists of three separate domains: the empirical, the actual, and the real. The empirical domain covers the observations and experiences made, whether direct or indirect. The actual domain covers all the phenomena and events happening in real life, experienced or not. And the real, which is based on the claim that manifest phenomena and events do not turn up accidentally or individually, covers the underlying structures and mechanisms that, under certain conditions, support or cause actual phenomena and events. CR looks at the structures and mechanisms that create the phenomena as a primary task for science to uncover (Danermark, 2002).

CR distinguishes between closed and open systems. A closed system is at hand when reality's generative mechanisms operate in isolation and independent of other mechanisms. Two main conditions are connected to closed systems:

1. A closed system does not have any change or qualitative variation in the objects having causal powers. If there is a qualitative change in the object then we are dealing with other objects having different powers and mechanisms.

2. The relation between the causal mechanisms and the mechanisms in their environment that influence their mode of operation and their effects must be constant for the outcome to be regular.

If both conditions are met, then no new emergent powers or mechanisms develop. Both conditions are necessary to make it possible to produce regularity. However, a challenge with closed systems is that a stratified reality is an open reality. There is a difference between mechanisms at high level and mechanisms at lower level; lower level strata are easier to close than higher level strata. This is also an issue in the discussion of the differences between natural science and social science, in which the social sciences in general are more concerned with higher level strata where closure is not possible (Danermark, 2002).

Concrete things or events in open systems must normally be explained "in terms of a multiplicity of mechanisms, potentially of radically different kinds (and potentially demarcating the site of distinct disciplines) corresponding to different levels or aspects of reality" (Bhaskar and Danermark, 2006).

CR acknowledges that reality consists of different strata, that multiple causes are usually influencing events and situations in open systems, and that a pluralism of research methods is recommended as long as they take the ontological status of the research object into due consideration. CR appears to be particularly well suited as a metatheoretical platform for interdisciplinary, non-reductionist research (Danermark, 2002). This applies particularly to complex challenges at higher strata, such as climate change (Bhaskar et al., 2010). In such situations, monodisciplinary empirical studies that consider only those factors of influence belonging to the researcher's own discipline run a serious risk of misinterpreting these influences. Moreover, according to CR, the different strata of reality and their related mechanisms (that is, physical, biological, socio-economic, cultural and normative mechanisms) involved in, for example, climate change are situated in macroscopic (or overlying) and less macroscopic (or underlying) kinds of structures or mechanisms (Bhaskar and Danermark, 2006). By integrating the perspectives of multiple disciplines, one can create insights unattainable from the standpoint of a single discipline. For complex problems, it could be valuable to do interdisciplinary research by integrating various research and disciplines to create a new understanding.

Moving upward through these strata from the biological to the socio-economic, a central point is that each new stratum builds on the power and properties of the underlying strata—while at the same time obtaining completely new mechanisms. However, the underlying strata cannot explain the overlying strata, because there is an emergence of a new and unique occurrence (although the properties of the underlying strata are combined, qualitatively new objects come into existence, each with its own specific structures, forces, powers and mechanisms) at the higher strata.

In situations of interrelatedness between the four planes, we face what Bhaskar and Danermark (2006) characterize as a "laminated system", in which explanations involving mechanisms at several or all of these levels could be termed "laminated explanations" (Næss, 2010a). The multiplicity and complexity deriving from level, context and scale may result in the constitution of a laminated, and occasionally a necessarily laminated, system (Bhaskar and Danermark, 2006).

Bhaskar and Danermark (2006) contend that social life must be seen in the depiction of human nature as a four-planar social being, which implies that every social event must be understood in terms of four dialectically interdependent planes: material transactions with nature, social interaction between agents, social structure proper, and the stratification of embodied personalities of agents.

According to CR, structures (S) create mechanisms (M), which must be understood as interacting with other mechanisms, context (C), thus producing an outcome (O). That is, S+M+C=O (Danermark, 2002).

Xue (2012) stated that from a CR point of view objects possess powers and generate mechanisms which can cause something to happen. There is an internal and necessary relation between the nature of an object and its mechanisms. However, the existence of generative mechanisms does not necessarily imply that they can operate; whether a mechanism can be activated or not depends on certain conditions and circumstances. And although some mechanisms reinforce each other, others counteract one another, leading to different events or effects. Context is therefore important in CR: the relative importance and specific role of strata varies from the object under study, from case to case, and is always an empirical question. Connected to empirical case studies critical realism does not rule out the possibility of rather exact assessment of certain effects. But such effects only apply to the specific spatiotemporal context. Not all effects can be measured exactly and quantified, but some can. Because of the spatiotemporal contextual, predictions cannot be more than rather crudely applied in other contexts and must be seen only as tendencies given under certain circumstances. As such it could only be stated that objects have the tendency to behave in a certain way and that the empirical effects are contingently dependent on the circumstances. Such a perception of causality is a central point of CR ontology. CR seeks to uncover the underlying structures and mechanisms. This is fundamental different than looking at causality as empirical regularities, that automatically follow something else.

Figure 4 shows a model of how structures, mechanisms and events exist.

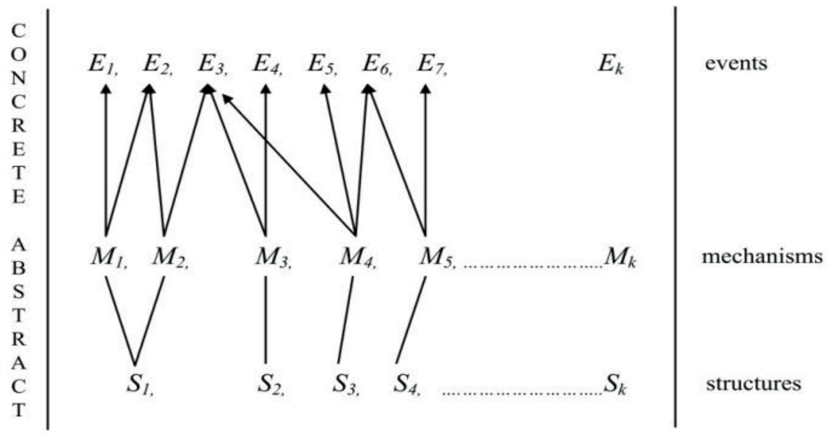

Figure 4 Structures, mechanisms and events according to Critical Realism (Sayer, 1992 p.117)

According to CR, mechanisms operate on several different leves of reality and possible order of scale (also called strata) which are hierarchically organized such as physical, biological, socio-economic, cultural and nomative kind of mechanism (Bhaskar and Danermark, 2006; Næss, 2010a; Xue, 2012). Each new stratum has the powers and mechanisms of the underlying strata as well as an emergent power that generates something new and unique and that cannot be reduced to the underlying strata. Those mechanisms within different strata of reality work toghether to produce concrete events. This implies that for a specific research problem at the higher strata, such as to study climate mitigation, attention for research cannot only be made at one level and overlook the mechanisms at other levels (Xue, 2012).

CR acknowledges the influences of both structures and actors. According to Archer (2003) structures emerge from the interaction of actors and have qualities that actors do not possess. In its understanding of the relationship between structures and actors, CR opposes these three types of reductionism (Næss, 2014):

- conflating up: Social structures are considered to reflect only the aggregated preferences among instrumentally rational actors (neoclassical economics, methodological individualism).
- conflating down: All human characteristics and capabilities other than those due to our biological constitution could be considered derived from sociocultural systems (certain types of discourse theory).
- central conflating: Structures and actors constitute at a mutual level and cannot be separated (Giddens' theory of structuration).

Actors have qualities in the form of social structures qualities as well as qualities that no social structure possesses. This allows the studying of the interaction of structures and actors over time by an endless cycle of developing structural conditions, social interaction and structural development. Structural conditions do not enforce or determine an actor's actions, but they do have an objective influence that reduces their degree of freedom. A key point is that actors and structures do not stand in a one-to-one relationship, but that society consists of several levels and emergent structures. Actors are confronted by not just one but by a network of interlinked political, economic, scientific, cultural, and other structures. Because structures exist prior to social interactions, actors normally do not create social structures from scratch[1]; they recreate or change structures through their activities (Buch-Hansen and Nielsen, 2005).

I argue that the use of non-reductionism and interdisciplinarity is well suited to understanding the transfer effects addressed in this thesis. For example, the main focus has been on energy economics and measurement of the so-called direct rebound effects within a positivistic research paradigm where quantification of the size of the rebound effect has been the focus. However, rebound effects manifest themselves on multiple scales (individual, household, firm, and industry) and levels (local, regional, national and global) and are discussed and understood within several disciplines (including economics, psychology and urban planning) and theories (including social and technical structures, socio-psychological, ecological economics, complex adaptive systems). Therefore, one point of departure of this thesis is its reflection on the connection between different causal mechanisms, levels, and dimensions where qualitative consideration is also seen as a valid science. It is important to interpret rebound effects and other transfer effects not as empirical regularities but as tendencies found under certain circumstances.

[1] It could of course be imagined that some actors created an entirely new type of social structure within some field or sector. But this is normally not the case; it is more common that existing structures are being maintained or modified.

Further, when assessing the environmental impacts from transport, the focus has been on direct emissions that other parts of the life cycle are missing and consideration of trade-offs between emissions categories has been left out. A CR approach would in that respect consider trade-offs from a life-cycle perspective for alternative fuel and vehicles, including the energy use and emissions associated with infrastructure. CR means, in my covering essay, also to look at energy use and emissions beyond national demarcation to account for the role of international transport. Other questions remain. For example, transport is influenced by multiple mechanisms at various levels. Do different drivers of energy use and related GHG emissions in the transport sector contribute in different directions? Some of the drivers might have strongly accelerated this effect, while others have mitigated it. CR points to the need to study such underlying mechanisms and the interrelationship between different mechanisms.

5. RESEARCH DESIGN AND METHOD REFLECTIONS

In this section, I give an explicit presentation of the research design, methodology, and the reasons for my choice of methods. In the previous section, I outlined my philosophical point of departure, which highlighted the need to look at complex problems, such as transfer effects associated with transport from a non-reductionism multilevel and an interdisciplinary perspective, and the importance of context; for example, should results be stated as tendencies under given conditions in time and space rather than as empirical regularities. Context is also important in method selection; the appropriate method should be selected in accordance to the phenomena under investigation and not vice versa. This `worldview` (Creswell, 2013) shaped my approach into the research conducted in the various papers and the selection of methods and theories and the interpretation of findings.

A research design is defined as the approaches or procedures of inquiry, which involves a selection into how studies are conducted. These approaches are normally understood to be done qualitatively, quantitatively, or as a combination of the two (Creswell, 2013). It can be understood in the same way as methodology. Methodology is about how actual scientific knowledge is obtained and may cover abstract issues about what science is, or is not, as well as more concrete issues on the very practice of scientific efforts (Bhaskar et al., 2010). The connections between philisophical basis, methodology and research methods used in this thesis are shown in figure 5.

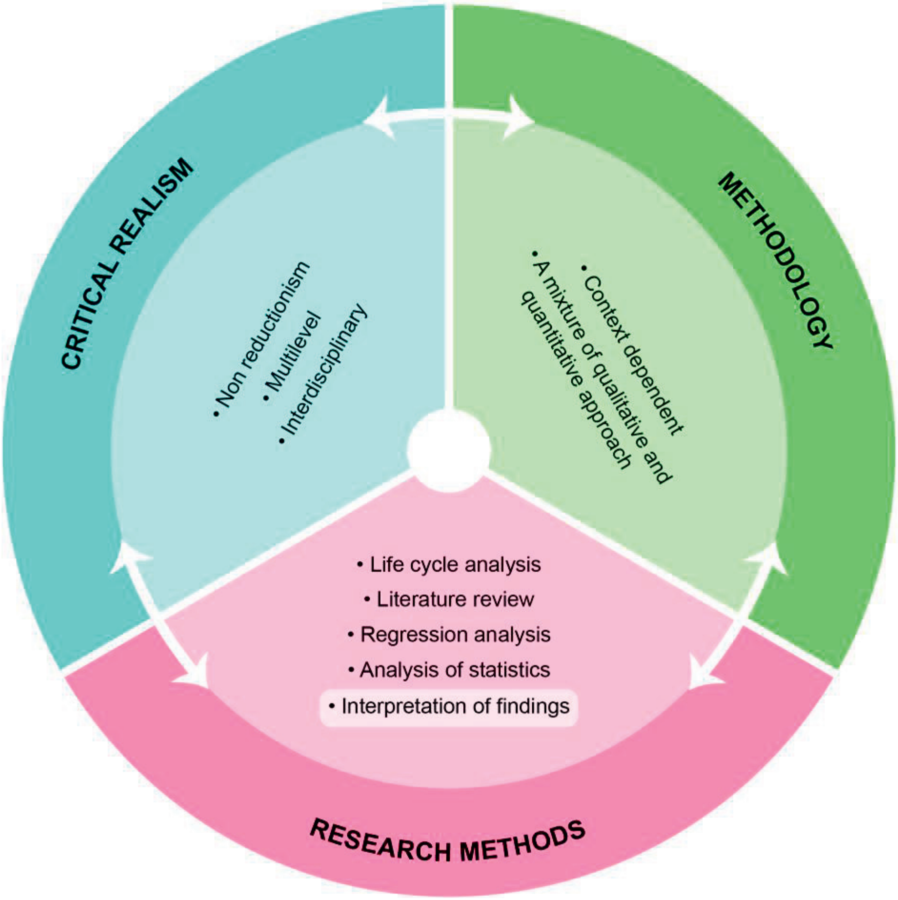

Figure 5 The connection between philosophical basis, methodology and research methods which I have applyed in my thesis (figure is inspired by Cresswell 2013 p. 5).

My thesis has been written through a collection of papers. However, it should be noted that each paper was related to different research projects. A coherent research framework was not available for all the papers taken together. However, papers 1 and 2 provided the impetus for paper 3, and paper 4 was the impetus for paper 5. Some similarities in the objectives are seen across the articles:

- To uncover partly overlooked environmental issues in transport research with novel cases
- To gain an understanding of the size of energy use, CO_2 emissions and GHG emission associated with transport, and to go beyond what was directly observable to understand growth in transport emissions

- To gain insight into transfer effects (papers 4 and 5 must be seen together on this topic)

The following methods were applied in the papers:

- Life cycle analysis, using data from life cycle emissions databases (papers 1 and 2)
- Literature review (all papers), more extensive in paper 3
- Multivariate regression analysis, using data from an online transport planning system (paper 4)
- Social science methods, including structured dialog with truck drivers to obtain feedback on the interpretation of the multivariate regression analysis (paper 4)
- Statistical analysis connected to understand drivers for goods transport (paper 5)

As outlined above, I have used several methods - which were selected on their capability and suitability to fulfill the research intentions. Quantitative methods and data were used in all of the papers (with the exception of paper 3); however, in each paper, the quantitative data was clarified, interpreted and explained by means of qualitative analyses applying the relevant theories and literature (Xue, 2012). The papers also highlight limitations connected to the use of statistics, for instance that findings cannot be interpreted as being law-like empirical regulations (Næss, 2004) and that phenomena under investigation cannot be extrapolated to other contexts. Furthermore, my interest in the totality of the papers was to gain insight into why transfer effects occur, the underlying social structures, and relations that cause transfer effects. See for example paper 5, in which we explored the indirect, direct, and response drivers for road freight transport. Also, I am interested in observing and interpreting transfer effects in a new way. An example here can be seen in paper 3, where rebound effects were coupled to the sustainable mobility discourse.

In the following, I present the research operations that were used in the papers and discuss the strengths and weaknesses of the cases, methods, data and their relevance in answering the research question in the covering essay.

In the first paper, we applied a simplified life cycle analysis (LCA), only accounting for CO_2 emissions; normally such an analysis includes several impact categories like land use, resource extraction, and energy use. A life cycle perspective takes into account all emissions from cradle to grave for transport, including infrastructure as well as the life cycle of the fuels. The main source of data used in the life cycle analysis came from Chinese statistics and different life cycle emissions databases (Probas and Ecoinvent). In addition, the direct emissions factor for ship transport was obtained from Whall et al. (2002) and from DEFRA

(2008) for flights. This information was combined with a literature review of papers connected to the-state-of-the-art policy process for international aviation and shipping as well as of the discourse on consumption-based GHG inventories.

A special consideration in this paper was the quality of data, especially that of the Chinese statistics. In the article, we suggested that the Chinese statistics should indeed be used with caution. A related issue was how to allocate China's CO_2 emissions from exported goods to individual destination countries; other authors have also had this difficulty for example Wang and Watson (2007). Our approach of allocating commodities exported to different world regions on the basis of goods shares in tons could obviously have led to errors in the results. Many of the goods exported to Hong Kong, China's second largest exporter from mainland China are re-exported to other countries after performing the value-added process; the same goes for Singapore, which is the seventh largest receiver of exported goods. As a result, the potential error with our approach can be relatively large.

Even if we calculated CO_2 emissions associated with China's exported goods, it can be argued that the most significant energy use and related CO_2 emissions associated with a consumption perspective would most likely be transport generated within exporting countries, which we did not address in the paper. We omitted inland traffic generated by import and export; a considerable share could probably be allocated to other countries than China by using a consumption perspective for GHG accounting, which could actually be much more important than oversea transport (International transport forum, 2013). This paper yielded the following valuable insights that can be used in a further discussion of the research questions:

- Importance of viewing transport in a life cycle perspective.
- The lack of accounting of the emissions in international aviation and shipping.
- Differences between the production and consumption perspective.
- Size of CO_2 emissions associated with international transport from China is not considered in policy making.

In the second paper, we performed an energy chain analysis based on a critical analysis of various literature sources and life cycle databases. In this case, it was mostly Probas and in some cases Ecoinvent. The energy chain analysis consisted of three parts: (1) the net direct energy use (the energy required for vehicle propulsion); (2) the gross direct chain, which includes the net direct energy consumption plus the energy required to produce it; and (3) the indirect energy chain, which includes the energy consumption for production, maintenance, and operation of infrastructure plus manufacturing of the vehicle itself. We analyzed different vehicle powertrains and fuels on the basis of the following assumptions:

1. The feedstock must be available in large quantities, and the alternative fuels (alternative in relationship to conventional fossil fuels, petrol, and diesel) must have an expected potential for the mitigation of environmental impacts.
2. The alternative powertrains must have an expected potential for the mitigation of environmental impacts.
3. The technologies must have the potential to be commercially viable.

A challenge with this kind of study is to get consistency in the geographic locations since many different sources of data are used and it is important to be transparent in our studies. The impact from infrastructure construction, maintenance, and operation will differ somewhat between countries according to the proportion of tunnels and bridges. In addition, the allocation of infrastructure on different transport modes that share it may be different in different countries, depending on characteristics such as road curvature, gradients, and the maximum allowable freight load. We based our analysis of road construction on Norwegian conditions. Other parts of the study, such as driving cycle and analysis of feedstock, could be said to be more related to a general European context.

A critique of our approach is that we did not include end-of-life treatment. However, recycling was not omitted from the analysis. Other studies have indicated that the impact of scrapping is minor for energy use and climatic gas emissions (Schmidt et al., 2004; Spielmann et al., 2007). Ideally, our analysis should have included more impact categories (other than energy use and GHG emissions) from both a life cycle analysis and a sustainable mobility point of view. Relevant indicators for passenger transport should include other air emissions (NO_x, SO_x, VOCs, PM) as well as other impacts (e.g., biofuels and water consumption). In addition, SO_2 and NO_x as well as particulate matter are important parameters.

It should be noted that the allocation procedure had a huge impact on our result. We used an attributional LCA and allocated emission on the basis of energy; however, different allocation procedures and an application of the consequential approach with its close link to marginal economic thinking would have given different results, for example, depending on how electricity mix in a Norwegian context was accounted for. In other words, electrical passenger cars would have been less favorable than what we presented in this study under other allocation procedures and contexts. Also, this type of analysis was on a per unit basis, which implies that the effect, for example, of large-scale implementation of electric cars and their impact on electricity consumption was out of scope.

This paper yielded the following valuable insights that can be used in a further discussion of the research questions:

- Transfer of environmental problems by category as well as through the life cycle of alternative passenger cars is highly likely.
- Many biofuel alternatives have low GHG emissions, but a high energy use.
- Alternative fuels and powertrains do not in themselves provide a road toward sustainable mobility because they transfer environmental problems and do nothing to lower mobility volumes.

In the third paper, we conducted a literature review of rebound effects from different theoretical perspectives to learn how the different perspectives have contributed to the scientific discourse. Our aim was to integrate the knowledge to provide a new framework of understanding (Høyer and Næss, 2008). We looked closely at the evidence, methods, assumptions, and reasoning and also studied different aspects of the rebound effect so that a single perspective, method, or aspect did not take priority (Longino, 2002). A key question was how we assessed the validity of our sources. We chose to include peer-reviewed literature, published scientific books, and project reports from research institutes as well as both theoretical and empirical work. We found the included work to be relevant in providing for a broader and interdisciplinary understanding of rebound effects. We found it more valuable to study rebound effects from the lenses of several disciplines than by a monodisciplinary approach, since it enables rebound mechanisms to be better understood and revealed. By looking at recent contributions that included several disciplines, we found that more rebound mechanisms were revealed; however, empirical research on rebound effects still needs to be conducted on the validity and the applicability of these perspectives in various contexts.

This paper yielded the following valuable insights that can be used in a further discussion of the research questions:

- The connection between rebound effects and sustainable mobility.
- The first overview of how different disciplines have dealt with rebound effects.
- A theoretical and methodological discussion of the different positions.
- Provides a fundamental understanding of the mechanisms that generate rebound effects.

In the fourth paper, we conducted a case study of a Norwegian heavy-duty truck transport company; we used multivariate regression analysis and the corresponding mean elasticity analysis to determine what influences fuel consumption. The truck company used Dynafleet, an online transport planning system that records daily fuel consumption and driving behavior. It should also be noted that during the project period (2010–2012), four meetings were held between drivers, transport planners and researchers in which the researchers presented their preliminary analyses. The aim of the meetings was to have a common understanding of the analysis and interpretation of the results and to discuss how the company could use the results. Since our regression analysis could only reveal correlation and not causality, we needed input from the drivers as well as from previous literature to interpret our findings. The drivers' experiences helped to identify errors and which variables to include. We found that variables associated with infrastructure have effects that are 10–12 times higher than variables attributed to driving behavior. The findings from the paper were context dependent and cannot be generalized to other vehicle classes or to other terrain and infrastructure conditions; for example, that better roads would be beneficial, because the total environmental impacts associated with infrastructure improvements will also depend on newly generated traffic. In addition, indirect energy (i.e., the energy needed for building roads) needs to be addressed. Out of scope were possible rebound effects associated with increased fuel efficiency.

This paper yielded the following valuable insights that can be used in a further discussion of the research questions:

- The relative importance of technical, infrastructure, and human factors on the potential for reducing fuel consumption at the company level.
- Specific case information about what decides fuel consumption at the micro level that could be used in a joint discussion with the findings from paper 5.

In the fifth paper, we conducted a literature review and processed and applied statistical sources from Statistics Norway in a novel way. The objectives of this study were to develop a theoretical model of the growth in road-freight transport in Norway in the period 1993–2013 by identifying the likely drivers of such growth and to reflect how these drivers contributed to the growth in energy use and GHG emissions. However, it was difficult to find responses aimed at reducing GHG emissions and energy use in freight transport. The measures most often reported for road transport were mostly associated with passenger transport. Many challenges and shortcomings were found in the data, such as a break in the statistical time series; a new standard was introduced in 2007, and it was difficult to deduce how commodities were allocated between the new (2007) and the old (1993) standards. It was especially challenging to account for indirect drivers in the model. We could not determine whether there was a switch from road to rail transport since most of the goods transported by railway were classified as either "grouped goods" or "unidentified goods." Another challenge was that we were not able to determine the true distance that the goods were moved. Information about the handling factor was not available (i.e., how many times goods are lifted to a new transport mode or vehicle).

This paper yielded the following valuable insights that can be used in a further discussion of the research questions:

- Increased understanding of how the road transport system functions and how indirect, direct, and response drivers influence energy use and GHG emissions.
- Increased understanding of potential rebound mechanisms and trade off effects associated with measures that aim to curb energy use and GHG emissions from road freight transport.

One major omission is the number of impact categories addressed in the papers. We either focused on CO_2 (paper 1), energy use (paper 3) or on both energy use and GHG emissions (paper 2,4 and 5). Although these were important, ideally other challenges connected to transport-associated transfer effects should also have been addressed. For example, local and regional pollutions, such as NO_x and particulate matter, the problems of direct and indirect land use should also have been considered, as well as resource problems connected to transport, such as non-renewable resources like metals, oil, gas and coal.

Table 3 summarise how the different articles related to diciplines, theories and scale. It could in general be said that all papers deal with human environment interaction.

Table 3 Summary of papers theory, scale and diciplinary position

Paper	Discipline	Theory	Scale
Paper 1	Combination of social science oriented (conceptual analysis) and technological oriented (life cycle analysis)	Life cycle theory, theories on consumption and produtction perspectives on GHG accounting.	International
Paper 2	Technological oriented and statistics	Life cycle theory	The passenger car, measured as emissions per vehicle kilometre
Paper 3	Conceptual analysis mostly associated with social science tradition	Uncover different positions such as: thermodynamics, transport planning, Social psychology, Socio-technological interaction, energy economics.	Several, deals with the duality between the micro and macro level
Paper 4	Statistics explained by means of qualitative considerations	Theory of statistics	Company level
Paper 5	Statistics which is interpreted by means of qualitative considerations	Rebound theory, decoupling theory	National level

6. TO WHAT EXTENT CAN TRANSFER EFFECTS EXPLAIN WHY ENERGY USE AND GHG EMISSIONS IN THE TRANSPORT SECTOR HAVE KEPT RISING?

Concerning the first research question in this covering essay, I will discuss how the three different transfer effects – geographical transfer effects, environmental trade-off effects and rebound effects – could explain why energy use and GHG emissions in the transport sector have kept rising.

6.1 GEOGRAPHICAL TRANSFER EFFECT

The increase of emissions in one country that result from reduced emissions in another country, called geographical transfer effects, is well-known and is usually understood to result from the shift of industrial production from western countries to the rest of the world, with China as one of the most important countries in this respect. A challenge arises from the global increase of goods and commodities that drives both national and international transport. "Late modern consumption societies" continue to purchase industrial and consumer products, while the production is moved to other countries. Including a life-cycle perspective (from cradle to grave) on global chains of consumption shows that western societies are still material intensive and that they have merely transferred their GHG emissions to other countries (Høyer, 2010).

Most of the analyses of GHG emissions have had a national (territorial) approach that focuses on emissions from production and that addresses only two consumption categories: fuel use by private residences and cars. However, in open economies there is little overlap between production and consumption within countries. Countries with no heavy industry may appear to have low GHG emissions, but could in fact due to consumption of imports, all with embedded GHG emissions have a greater environmental impact. Thus, an analysis based only on production ignores the large embedded emissions of the imports, thus, it is essential to also employ a consumption perspective. The Kyoto Protocol calculates GHG emissions by nation (geographically demarcated territories), taking into account emissions from the production of goods as well as emissions due to energy use in residential housing and travel by private car or motorcycle. The Kyoto Protocol's accounting methods disregard aspects of domestic consumption other than residential housing and private car travel, and this has been widely criticized (Aall and Hille, 2010). A rich country that imports much of what it consumes might appear to be progressing towards compliance with the Kyoto Protocol when, in fact, it has simply shifted its environmental impacts to the nations that produce the goods. Thus, many have argued for calculating GHG emissions inventories based on consumption (Helm et al., 2007; Munksgaard and Pedersen, 2001; Peters and Hertwich, 2008).

In my thesis, I am concerned with transport-related energy use and GHG emissions that are caused by this “export” of production from high-consuming nations like Norway. None of the previous literature has provided a detailed analysis of the role of transport in production-/consumption-based comparisons of emissions. Although references to transport have been made (Hertwich and Peters, 2009; Peters and Hertwich, 2008), emissions from international aviation and shipping are neither accounted for by any nation nor part of the Kyoto Protocol. Some initiatives have been taken after 2010 in how to curb GHG emissions associated with international transportation. The organizations in charge of addressing these emissions are the International Maritime Organization (IMO) for shipping and the International Civil Aviation Organization (ICAO) for aviation. In 2011, the IMO adopted a mandatory GHG reduction standard measured via the energy efficiency design index (EEDI). The EEDI implies a minimum energy efficiency level per capacity mile for different ship types. The goal, targeted at the construction of new ships, is to have the per-ship capacity level (such as per-tonne mile) drop by 10% in their use phase. The ICAO has taken a similar initiative for aviation: newly produced aircraft are supposed to fulfill the engine certification standard. There have also been initiatives for market-based measures in which the principle is to implement reduction in emissions at the lowest cost, given incentive to invest in sectors where cost of abatement is low (Anger, 2014). The European Union has tried to diffuse the idea of the European Union Emission Trading Scheme (EU ETS) into an international global model for aviation. However, an international power struggle in which the United States, Russia, India and China opposed the scheme, and China threatened to cancel Airbus aircraft orders, led to pressure from the aircraft industry in France, Germany, Spain and the United Kingdom to change their governments’ opinions. The European Union now wants to find a solution within ICAO by 2016 (Anger, 2014; Lindenthal, 2014).

The emissions associated with Chinas exported goods minus imported goods is approximately 110 Mt CO_2. This indicates the scale of the emissions associated with the globalization of production and growth in transport (Andersen et al., 2010). However, not only international transport but also transport within countries is affected by this globalization process. The transport work of truck transport in China has increased by 13%-18% per year for the period 2008-2011, and in 2011 amounted to 5.100 billion ton-km (International transport forum, 2013). This means that in China, truck transport per capita is now at the same level as in Norway, despite China’s much lower GDP per capita. Much of the transport in China is for domestic consumption and investment, but manufactured exports, including exports to Norway, are significant. However, this should be reflected on to get the whole story about the influence of external trade on domestic truck transport. Goods that are imported by ship are often sent onward from the harbor by truck, which is considered domestic lorry transport. Likewise, goods that are imported by border-crossing trucks or trains may be unloaded at a terminal quite close to the border for onward distribution, sometimes across the whole country, by truck. Also, exports may be moved by domestic trucks to a harbor for shipment abroad or to a depot before rail or truck transport to other countries.

There have been some initiatives in international ship and aviation transport to curb energy use and emissions, but these initiatives are likely to be flawed if their goal is to substantially reduce GHG emissions from shipping and aviation. The IMO initiative addresses newly built ships, as do the engine efficiency initiatives by ICAO for aviation. However, the relatively long average life of ships and airplanes (15 to 30 years) compared to, for example, road vehicles (5 to 15 years), implies the need for a long implementation time for technological improvements to produce any real effects. Also, there is a possibility that the proposed efficiency measures could lower transport costs, causing rebound effects. Even if market-based mechanisms have not been introduced in international shipping and aviation, such measures could be questioned. Gössling and Cohen (2014 p. 201) concluded that "the EU ETS is thus unlikely to have any de facto importance for airlines and growth in aeromobility" because the EU ETS makes it possible to buy credits where abatement costs are low; that is, emission reduction will be achieved in other sectors, thus the volume of air traffic will continue to grow (Ares, 2012).

Consumption-related GHG emissions are better suited to account for the real emissions associated with transport and other consumption activities. This would reveal the cases where an apparent decoupling in reality is about shifting GHG emissions from one country to another, thus also illustrating the need for substantial changes away from the goal of continuous economic growth. The policy strategies proposed by IMO and ICAO are in line with school of ecological modernization, in which curbing GHG emissions should be achieved by improved technological efficiency or by the market. We found that international transport itself contributes to large CO_2 emissions, and if we include how this international transport affects inland goods transport related to production for consumption elsewhere, its contributions would likely be much higher.

On the basis of what is outlined above, I will argue that GHG emissions generated from international transport should be accounted for and be curbed. Inland transport generated for production for consumption elsewhere should also be included in discussions about consumption-based GHG emissions.

6.2 ENVIRONMENTAL TRADE-OFF EFFECTS

We used a simplified life-cycle analysis (LCA) as well as an energy-chain analysis in paper 1. Both methods consider the life cycle and are normally used to assess the energy, resources or environmental performance of a specific technology or to compare different technologies. LCA is often defined as being part of the school of ecological modernization (Spaargaren et al., 2000), as the main focus of this school of thought is on reducing emissions on a per-unit level. In that respect, LCA can be seen as taking a reductionist perspective in relation to environmental problems, since it can be used to legitimize products that are actually harmful in a wider perspective. Improvements that are “freed up” from efficiency, such as money and time, can be used to increase production and consumption. Moreover, even a comparatively benign product will be damaging if produced in a sufficient volume, and LCA does not take the volume issue into account, such as the total GHG emissions from the transport sector. However, in recent years, researchers have adopted some new methods and wider perspectives, such as input-output analysis, consequential LCA, and the investigation of indirect land-use change. This broader perspective connects LCA with considerations of society-wide rebound effects, and thus loosens the bonds with the school of ecological modernization.

However, even if the focus of our analysis was to find energy-use numbers for passenger cars in a life-cycle perspective expressed in the unit per vehicle kilometer (paper 2), the numbers on a per-unit scale could be scaled up to determine the approximate emissions as we did for China’s exported goods. The inclusion of the life cycle turns the attention to an understanding of energy use and GHG emissions associated with transport systems rather than only considering the direct emissions from vehicle propulsion.

Most studies on emissions from transport have focused on a single alternative fuel or technology (Hawkins et al., 2013). Some studies have also compared the life cycles of alternative fuels (Concawe, 2006; Delucchi, 2005; Høyer and Holden, 2007; Weiss et al., 2000). Only a few studies have analyzed the entire transport system in a life-cycle perspective (Chester and Horvath, 2008; Simonsen and Walnum, 2011). Paper 2 addresses three life cycles of passenger car transport—namely, the life cycle of the fuel (fuel feedstock, its transformation into fuel useful in a car, use of the fuel for the propulsion of the car), the life cycle of the car (production and maintenance) and that of the involved physical infrastructure (production and maintenance of the road).

Commonly discussed for mitigating GHG emissions in the transport sector is the potential for less carbon-intensive “low-emission” or “zero-emission” vehicles that reduce emissions per vehicle kilometer traveled. Our paper included an assessment of eight biofuels. We found that paradoxically, some of these biofuels had relatively high GHG emissions (biodiesel produced from animal fat, biodiesel produced from soybeans, and biofuels produced from rapeseed). In addition, all biofuel alternatives we analyzed had a relatively high energy use when their life cycles were considered. High energy use is most likely a sign of other environmental challenges and indicates direct and indirect land-use changes that were outside the scope of our study, even if they are crucial categories connected to biofuels. We found a trade-off effect between energy use and GHG emissions for alternative fuels and powertrains when considered in a life-cycle perspective, which was especially evident for the biofuels we considered.

The European Union has translated the challenges associated with biofuels and their life cycles into policy as part of the European Commission Sustainable Directive (European Union, 2009). This policy specifies that sustainable production of biofuels requires that its raw material must not be grown in areas important for biodiversity or in soil with a high fixed-carbon content, such as in wetlands. Furthermore, the production of biofuels must prove to significantly reduce GHG emissions by at least 35% in comparison with fossil fuels. In 2017, this requirement for emission reduction will increase to 50% (ibid.).

Another main finding was that in a Norwegian context using hydro as an energy source, we found electrical cars to have a favorable score on both energy use and GHG emissions. However, the choice of energy source (e.g., hydro, fossil fuel, nuclear energy), that is, applying a different electrical mix, gives less favorable results for electrical cars (Hawkins et al., 2013). A challenge could also be found in large-scale implementation of electrical cars, since it could lead to an increased demand for electricity, which could create an additional need for electricity and new power plants, not unproblematic from an environmental point of view, because of land use and resource use. GHG emissions and energy use rise along three life cycles, namely that connected to (1) the vehicle itself, (2) the fuel used by the vehicle and (3) the involved physical infrastructure. There is a trade-off effect between energy and GHG emissions, which suggests that the requirements for sustainable mobility can be achieved only through lower mobility with passenger cars. The paper addresses some of the shortcomings in the strategy to limit the effort of achieving sustainable mobility to that of changing vehicle technology. Alternative fuels and powertrains did not appear to offer any solutions to volume problems associated with person transportation. These two challenges make it hard to see if alternative fuels and innovative technologies for person transport can drastically reduce energy use and GHG emissions—any solution probably has a trade-off connected to other environmental impacts. Achieving sustainable mobility, with a fundamental reduction in energy use and related GHG emissions will remain a challenge as long as mitigation strategies do not address the cause of the problem, that is, the continuous growth in the volume of transportation.

6.3 REBOUND EFFECTS

Rebound effects have been treated in papers 3 and 5. What exactly is a rebound effect? According to the *New Oxford American Dictionary* (Kindle edition, (2010), a rebound is

> “something that bounces back after hitting a hard surface or object, recovers in value, amount and strength after a previous decrease or decline, or has an unexpected adverse consequence for the person responsible for it”.

In short, a rebound sets you back when compared to the effect that you initially tried to achieve (Levett, 2009).

Traditionally, research about rebound effects has been performed on energy use within an economy tradition, in which the size of the rebound effect is seen as the difference between the original engineering estimate and the net energy savings after implementing more energy efficient technologies. An overall rebound effect of 100% means that the expected energy savings are entirely offset, leading to zero net savings.

Within energy economics, a rebound effect is understood as a behavioral change that follows an efficiency improvement. Consumption and production after an efficiency improvement will not necessarily follow the “engineering estimate,” because according to simple micro-economic theory, consumers and producers will adapt to price changes following energy-efficiency improvements (Sorrell, 2007). Looking more deeply into the issue from an energy-economics perspective, on the micro level, improved energy or material efficiency might enable firms to raise wages, to increase dividends or to lower prices, leading to increased net consumption. Similarly, induced technological savings by individuals are redirected to other forms of consumption, canceling some of the initial gains (Wackernagel and Rees, 1996). Thus, it is necessary to distinguish between a micro- and a macro-level economic perspective. The micro-level deals with how an atomistic individual consumer in theory might respond to a rebound effect. At the macro level, the effects of efficiency gains could increase energy consumption by making energy cheaper than other inputs and by increasing economic growth. Technical efficiency gains that produce increased return on capital will attract investment and ripple through the economy; this was exactly the point that Jevons (1865) made.

The origin of the concept is often attributed to Jevons (1865). After looking at different strategies to solve the United Kingdom’s problem of running out of coal, he concluded that (p. 140) “it is the very economic use of coal, which leads to its extensive consumption”: If the quantity of coal used in blast-furnaces are diminished in comparison with the yield this will lead to increased profit from trade, more demand and higher overall coal consumption. He also pointed to an indirect effect that progress in one branch of manufacture generates a new activity in most other branches. A similar argument was made by Khazzoom (1980 p. 23) who focused more on the micro level, stated that "after increased productivity comes a decline in the effective price of commodities, and that in the face of lower effective prices, demand does not remain stagnant at its former level (of 100 units), but tends to increase". In another paper Brookes (1990 p. 199) criticized that energy efficiency could be used to curb the greenhouse effect since "reductions in energy intensity of output that are not damaging to the economy are associated with increases, not decreases, in energy demand at the macroeconomic level". On that background, Saunders (1992 p. 135) formulated the so-called Khazzoom–Brookes postulate in the following way: "With fixed real energy price, energy efficiency gains will increase energy consumption above where it would be without the gains." The Khazzoom–Brookes postulate explains the backfire phenomenon, in which the benefits from energy efficiency savings would disappear after the energy efficiency improvement was made. Saunders postulate states that rebound effects would be greater than 100%.

Following these research works, the size of the rebound effect has been fiercely debated. Three different positions could be found in this debate:

- Rebound effects are *limited*, due to demand saturation and negligible energy cost, and therefore are of minor importance (Lovins, 1988; Schipper and Grubb, 2000)
- Rebound effects are of at least *some* importance, but they need not result in energy efficiency polices becoming substantially ineffective (Sorrell, 2007).
- Rebound effects are *significant*, and improving the efficiency of energy use might not lead to reduced energy use nor be an effective policy for reducing GHG emissions (Saunders, 1992).

The dominating research approach on rebound mechanisms during the past 35 years has been that of energy economics, which explains the occurrence of rebound effects by referring to both the income and substitution effects, and which interprets the behavioral model of the rebound effect as solely an economic one. From 2008 onward, there has been an interest in understanding rebound effects beyond energy economics (Giampietro and Mayumi, 2008; Peters et al., 2012; Santarius, 2012). In this alternative approach, it is stated that rebound effects have been neither well researched nor understood so far, and that a wider approach than that of "energy economics" and "the economic man" has to be applied. Our research took place in this understanding and looked at how we could comprehend the rebound effects through the eyes of interdisciplinary research.

We found in paper 3 that most of the attention in current research on possible rebound effects taking place within the transport sector has been on the direct rebound effects of increased fuel efficiency and reduced fuel costs in the form of an accompanying increase in person transportation work. Most of these studies are from the United States and Europe. Typically, the direct rebound effect is found to range from 10 to 30% (Sorrell, 2007). Large variations among these studies occur, which could be due to differences in the choice of system boundaries in the studies in question, that is, differences in the choice of time periods, methods for calculations, and geographical scope.

Some studies have addressed the evolution of cars, particularly the change in car size (Giampietro and Mayumi, 2008; Ruzzenenti and Basosi, 2008a, b, 2009). Others have addressed the time dimension, that is, how faster (and more comfortable) modes of transport have affected emissions from transportation (Spielmann et al., 2008). Some have highlighted that infrastructure development, such as wider roads, could generate traffic growth (Næss et al., 2001; Noland and Lem, 2002), a mechanism that is now recognized among transportation researchers. The latter rebound effect relates to the fact that road capacity improvement can immediately improve energy use and emissions per vehicle kilometer, but as traffic grows due to the improved driving conditions, the total energy use and GHG emissions may increase.

In our paper we addressed the following perspectives: energy economics; ecological economics; socio-technological; urban and transport planning; socio-psychological; and an evolutionary perspective. We found transport-associated rebound effects in the research literature within five of the six perspectives. The ecological-economics perspective has not dealt with specific sectoral rebound effects but rather with the probable size of the economy-wide rebound effect. We also examined the possibility of rebound effects associated with current strategies for sustainable mobility, and found examples of rebound effects associated with all three categories of sustainable mobility strategies in the scientific rebound discourse. Table 4 shows a simplified version of rebound effects connected to sustainable mobility strategies these relationships are described more thoroughly in paper 3.

Table 4 Examples of rebound effects according to different disciplinary positions

Perspective	**Description of rebound effect**	**Sustainable mobility strategy that the measure to lower energy use is mostly associated with**
Energy economic	Efficiency improvements in vehicles give cheaper cost of driving that could generate more driving and substitution away from cycling and walking.	Efficiency
Urban planning	Compensatory travel hypothesis has been proposed connected to residents living in densified urban areas. Thus, the suggestion that there is a limit to urban densification with regard to curbing transport volumes, since people make compensatory travels.	Reduction
Socio-psychology	Environmental benign behavior in everyday life, such as using public transport or walking and cycling, could lead to an indulgence effect while on vacation such as choosing long-distance flights.	Substitution
Socio-technological	Efficiency improvements associated with General Purpose Technologies, such as cars and planes, have contributed to change society so that economy-wide energy consumption has increased.	Efficiency
Evolutionary	Improvements in the performance of engines have the potential to lead to lower energy use; however, power enhancement of engines has been found, for example, by manufacturing a larger model of the same car.	Efficiency

The main outcome of the third paper is the conclusion that expanding on the research dimensions, perspectives and disciplines creates a better framework to comprehend rebound effects.

We concluded that different aspects of the rebound effect should be addressed in such a manner that any perspective, method or dimension takes priority over any other. We look at rebound effects from an interdisciplinary perspective to increase our understanding of the explanations for and the mechanisms of rebound effects. Our paper illustrated how different disciplines and theoretical perspectives have contributed to the scientific discourse on rebound effects.

We conclude in paper 3 and paper 5 that rebound effects in themselves are not the only reason that energy use and GHG emissions have continued to rise in the transport sector despite implemented technology changes and policy measures aimed at reducing energy use and GHG emissions. We must look beyond the rebound effects themselves and at the mechanisms that create rebound effects. How are time, space and money saved following efficiency or technology improvements used? Is it possible to avoid or even mitigate rebound effects in a situation of continuous economic growth? In an expanding economy, we find it likely that potential savings will be used for other activities; obvious examples are the preferences for faster transport and for bigger passenger-transport cars.

Another key question is whether it is possible or feasible to isolate a rebound effect by looking at only the cost effects of fuel efficiency, because there are close connections between economic growth, technological improvements (including comfort and efficiency developments) and increased energy use.

A specific issue associated with the understanding of rebound effects is the difference between rebound effects at the micro level and at the macro level. Clarifying these distinctions allows you to ask the pertinent question: How could something that is environmentally benign at the micro or company level turn out to be environmentally damaging at the macro level? I will illustrate the answer to this question using the findings in paper 4 and the theoretical perspectives in the other papers. We found in paper 4 that variables that were mostly associated with infrastructure and terrain had effects in terms of improving energy use per vehicle kilometer, 10–12 times higher than those of variables attributed to driving behavior. This suggests that the most efficient way to reduce energy consumption and GHG emissions from transport – at least at a micro level – would be by means of improving road standards.

However, the effects seen at a *macro* level must also take into account increases in the amount of traffic that result from the road improvements. There could be new total vehicle travels on improved roads either because of decreased travel time or because traveling is more convenient. Road improvements could also attract traffic from other routes and modes of traveling. This newly generated traffic as well as the energy use related to building, improving roads can offset some, or all of the initial energy savings connected to road improvements. The associated rebound effect could come from increased transport volumes, the energy use in making the road improvements, and in some cases, when energy use per vehicle kilometer once again starts to increase as traffic growth results in congestion (such as in an urban environment). Long-term effects can also be found for both passenger and goods transport; as transport becomes more efficient, the dependence on transport systems and a lock-in of land area as well as an adaptation to more mobility-dependent societies are probable (Næss et al., 2012; Noland and Lem, 2002; Victoria Transport Policy Institute, 2014) . Of course, this situation is context dependent and most likely to be seen in areas where roads are built to eliminate congestion and where the unmet demand for transport is likely to lead to new congestion. In addition, cases in which new roads have increased speed limits (to above 80 kph) will also lead to both increased energy use and increased GHG emissions. In other cases, however, improvements that increase speed may be beneficial (such as improvements to roads that required low speeds because of steep hills and curves), depending on the speed limits and traffic volume after the improvements. Some of these benefits would disappear if the energy required to build tunnels and new roads in challenging terrain were considered (Strand et al., 2009).

7. WHAT ARE THE SIMILARITIES AND DIFFERENCES BETWEEN THE TRANSFER EFFECTS?

In this chapter I will compare the three transfer effects “geographical transfer,” “trade-off” and “rebound.” One obvious similarity is that they all illustrate that proposed solutions or the lack of understanding of environmental problems could cause environmental problems elsewhere. Figure 6 below illustrates differences and similarities between the three transfer effects.

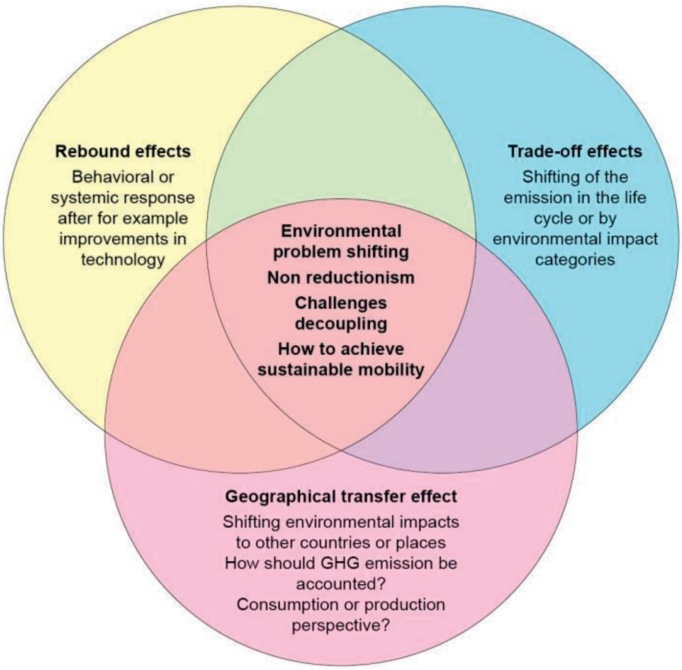

Figure 6 Similarties and differences between transfer effects

Transfer effects give a starting point to critically discuss the shortcomings connected to ecological modernization, and challenge the hypothesis that it is possible to decouple economic growth from environmental pressure. It is common to distinguish between *absolute* decoupling (e.g., when the transport volumes decrease and GDP increases) and *relative* decoupling (e.g., when they grow at different rates) (Sorrell et al., 2012). For example, there seems to be some agreement that the tonnage transported has recently increased less than GDP has in Europe, and that vehicle kilometers and emissions per ton-km have declined somewhat due to increased capacity utilization and use of larger trucks. However, by taking into account transfer effects, we can reveal that transport-associated emissions are considerably higher than what is shown in current environmental statistics. Possible rebound effects from technological improvements or policy measures that aim to curb energy use and GHG emissions are also absent.

Another similarity relates to the fact that these effects are largely overlooked in current transport research. One reason for this situation is the potential dominance of economics and positivistic research. It could be argued that transfer effects are difficult to study by applying reductionist research methods (one discipline or method), which may be less suited for studying complex and interrelated phenomena such as transfer effects. Research on rebound effects has, for example, been aimed at finding the correct size of the rebound effect based on economic theories. This research has mainly taken place within the discipline of energy economics, applying elasticity estimates and econometric analysis rather than trying to analyze the underlying mechanisms that create rebound effects.

Transfer effects contribute to the discourse on how to achieve sustainable mobility, since they should be taken into account regarding policy measures that aim to reduce energy use and GHG emissions from transport.

The three categories of transfer effects differ when it comes to areas of research and which type of transfer they address.

Geographical transfer effects are concerned with which system boundaries should be applied when calculating GHG emissions and energy use. The accounting method for measuring national GHG emissions given in the UN Framework Convention on Climate Change (UNFCCC) does not take into account life-cycle emissions and emissions from international transportation by air and ship. Thus, this way of producing national GHG emissions inventories mainly within national boundaries does not allocate GHG emissions based on consumption.

Trade-off effects involve the possibility of moving environmental impacts in time and space alongside the different lifecycle stages, and/or qualitative changes of environmental consequences from one impact category to another.

Rebound effects are concerned with behavioral or systemic responses to a technology shift or implementation of a policy measure, not including responses in the form of barriers to technology shifts or implementation of policy measures. The concept is most frequently discussed in connection with energy efficiency improvements but its connection to generated traffic, to resource use in general, and to green technology and environmentally friendly products is also treated in current research. The price of energy is not the only factor that explains changes in energy consumption behavior; environmental awareness, habits, and lifestyles are also factors that could explain rebound effects. Rebound effects also deal with the connection between micro and macro levels, and how the relationship between structure and agency could explain rebound effects and their underlying mechanisms.

8. TO WHAT EXTENT HAVE TRANSFER EFFECTS BEEN OVERLOOKED IN POLICY MAKING, AND WHAT COULD BE DONE TO MITIGATE THEM?

There are few policies that target mitigating transfer effects within the transport sector. There are, however, some initiatives to curb greenhouse gas (GHG) emissions in international aviation and shipping, such as the introduction of voluntary efficiency standards for the production of new ships and aircraft. Another example is the development of regulatory policies that establish sustainability standards for biofuels in the United States and in the European Union (EISA, 2007; European Union, 2009).

There are several reasons for the omission of transfer effects. Both transport research and research on transfer effects have been associated with economic considerations and both have been dominated by economic research, mostly related to positivistic research methods, such as finding the right economic instrument. Nevertheless, ignoring other disciplines with other perspectives can lead to omissions in understanding the systemic effects of proposed policy measures and can limit our understanding of the complexities associated with transport. For example, it can be difficult to determine the size of rebound effects, the context under which they are evident, and the research methods that should be used. Not knowing the exact size of rebound effects could make policy makers hesitant to take action.

Transport policy focus primarily on the hope that new and improved technologies will solve transport-related emissions. However, because the efficiency strategy does not address the indirect drivers of transport growth, it can result in policy responses aimed at reducing only direct emissions from vehicles. Furthermore, there seems to be a reluctance to take any measure that may curb transport growth; the 2011 EU white paper on transport *A Roadmap to a Single European Transport Area* states that "curbing mobility is not an option" (European Commission, 2011).

I have argued that sustainable mobility implies taking a global perspective and reducing both mobility and related energy use in financially rich parts of the world by a factor of three to five. In my introduction, I identified several drivers of traffic growth in both passenger and freight transport; the drivers are closely interlinked with developments of modern societies. Although the policy goal is an absolute reduction in the levels of GHG emissions from transport, the trend seems to be in the opposite direction.

In sections 3.3 and 3.4, I outlined both the ecological modernization position and the degrowth position. Ecological modernization is mainly associated with the efficiency strategy and the substitution strategy. The degrowth position question the idea of continuous economic growth. In that respect, degrowth also postulates the need to curb transport volumes, which are seen as a fundamental driving force for increased energy use and subsequent GHG emissions in the transport sector. I discuss how and to what extent these two positions differ in their approach to mitigating transport-associated transfer effects, but my main focus is on rebound effects.

A key point in ecological modernization is the internalization of the external costs of transport. Current environmental policies do not consider that energy consumption will grow as a result of lower costs that follow efficiency improvements (Arvesen et al., 2011; Santarius, 2012);. One way to mitigate rebound effects could be to increase the cost of energy after efficiency improvements have been implemented. Another proposed solution has been to make it more expensive the more the technology is used, for example, by making vehicle insurance and weight taxation dependent on distance traveled (Hvelplund, 2012).

Tradable permits have also been proposed. The concept of tradable permits includes, to some degree, an increased cost of energy use per unit and is further meant to introduce a ceiling, so that GHG emissions are compensated for in other sectors. However, a flaw in the current EU ETS can allow GHG emissions in the aviation sector to keep rising because the increased cost can be invested in other, lower cost sectors (Ares, 2012; Gössling and Cohen, 2014). The increased cost of aviation will probably not significantly change travel flows or reduce absolute emissions from transport (Gössling and Cohen, 2014).

In 2010, the Norwegian government established Transnova to fund projects that will implement environmentally benign technologies. The agency’s primarily focus is on the switch from fossil fuels to alternatives and its mandate includes awarding grants for infrastructure for recharging electric cars. It is assumed that alternative fuels will be inconvenient and expensive to use for individual users until everyone switches over. The inherent logic in Transnova’s approach is that rebound effects are not the problem and that we can solve transport-related GHG emissions simply by changing our energy system. In fact, if the current energy system is changed, then rebound effects would be welcome, because the new energy system will emit much less carbon (Hvelplund, 2012).

In summary, the ecological modernization position theorizes that transfer effects can be avoided by moving from current consumption patterns towards more efficient and environmentally benign ways of traveling. The policies to prompt such a move may include increased costs and taxes for current choices, subsidies to environmentally benign solutions, or increased costs for environmentally harmful alternatives.

From a degrowth perspective, there has been criticism of attempting to solve rebound effects by simply introducing higher taxes on energy, because the environmental value of this solution will depend on how the marginal tax revenues are spent. In a sustainable society, neither private consumption nor public spending can grow forever (Nørgård, 2013). Thus, as long as purchasing power remains the same or increases through economic growth, avoiding rebound effects (and transfer effects) seems to be impossible. Nørgård (2013) argues that rebound effects can be avoided only if labor or resource productivity increases and not turned into more production and consumption, but into other benefits, such as reduced work time, or by lowering labor productivity to balance the growing resource productivity. Alcott (2010) argues that policies that set absolute physical caps are the most efficient in curbing rebound effects.

Key questions in the degrowth point of view are whether absolute decoupling is possible for transportation and if the goal of achieving sustainable mobility is possible under conditions of growth. These suggest that solving transport-related transfer effects implies a fundamental reorientation of values and finding a different economic model that has wellbeing instead of GDP as the main goal.

One concrete measure to curb transport volumes and rebound mechanisms could be to lower speed limits, thus increasing the time it takes to travel a set distance. This could to some degree counteract the notion that greater distances can be covered within the same time budget (Givoni and Banister, 2013). Policies that restrict building new and improved roads could counteract that liberated road space after road improvements is filled by new traffic.

To sum up the degrowth position: the avoidance of rebound and other transfer effects probably needs a fundamental (global) change in society’s affinity for economic growth as an overriding goal. In theory, a shrinking economy implies that fewer goods will be produced and hence the volume of freight transportation and its accompanying energy use and GHG emissions may decrease accordingly.

Table 5 Proposed policies connected to transfer effects and their challenges

Policy	**What type of transfer effect?**	**Comments**
Internalize external costs from freight transport	Rebound effects	Can create a geographical transfer effect, since cost of transport is decided domestically
Vehicle insurance and weight taxation depend on distance traveled	Rebound effects	Does nothing about indirect rebound effects, how governments spend their revenue
Non fossil transport sector	All transfer effects	Can create tradeoffs in impact categories and in the various life cycles associated with transport. New problems will be evident if we do not curb current transport volumes
Tradable permits in international transport	Geographical transfer effects	Can lead to the offsetting of transport emissions to other sectors
Impact caps	Absolute physical caps on energy and resources	Will, in theory, implement a ceiling, which hinders transfer effects; real-world implementation is difficult
Resource productivity increases are used for less work time and more time spent on low impact activities	Rebound effects as well as trade-off effects	How to implement such a policy and the systemic effects of such a change is uncertain. Could cause sufficiency rebound effects, in which voluntarily savings by one country or individual can be offset by other countries or individuals
Lower speed limits	Could counteract rebound effects associated with travel time savings	Will most likely be connected to road transport. Just a reduction in speed limits on roads will not intercept the

		trend that some of the fastest increase is in per capita travels is by long distance flight
Curb investment in roads	Aimed at hindrance of generated traffic	This could be a challenge to implement because of the political system. where infrastructure performance is central for economic growth

9. CONCLUSION AND FURTHER RESEARCH

I found that policies that deal with transfer effects are scarce and that all of the proposed solutions both from the school of ecological modernization and from degrowth have their weaknesses (see Table 5).

In chapter 3.1, I compared different strategies or routes towards sustainable mobility. I find it likely that the efficiency strategy and economic growth are closely connected and that under conditions of continuous economic growth, there has been a tendency for any freed-up resources (time or money) to be used either direct or indirectly for more production and consumption. Efficiency measures do not change the structure of vehicle mobility; that is, it needs fuel and infrastructure provisions. Improvements in road standards or in vehicle technologies support existing infrastructure and create a situation in which current technologies and transport patterns are locked in.

Substitution to other transport forms can be beneficial if it implies choosing less polluting transport forms. In Norway, we have not yet seen a substitution of environmentally benign travel forms. That is, from car to public transportation for passengers; or freight transport from road to sea and rail.

According to Høyer (1999), a reduction of mobility is most in accordance with sustainable mobility, and substitution is more in line with sustainable mobility than efficiency. I argue that the avoidance of transfer effects should be part of the discourse on how to achieve sustainable mobility. Transport policies to reduce transport volume should be promoted. For example, using urban planning to reduce the use of cars in favor of more walking and cycling is sound but such measures must consider rebound effects such as the compensatory travel hypothesis, in which people living in urban environments tend to take more long-distance flights. However, in my opinion, arguing in line with Næss (2012), taxes and regulations that are directly aimed at rebound activities (such as increased prices for flights) are sounder than, for example, stop plans for urban densification.

It is difficult to see how mobility could be reduced without questioning the goals of economic growth or a fundamental reorientation of societal values and policy. According to Høyer (1999), substitution and efficiency are important parts of the route to sustainable mobility; however, curbing mobility levels is crucial. This calls for a shift from considering efficiency or end-of-pipe solutions to looking at the sources of those effects and rethinking economic growth and the social and political reasons for increased transport volumes. If the underlying causes are not addressed, I believe there is room for the occurrence of relatively large transfer effects. If transport volumes are maintained, it is highly probable that no major reduction in GHG emissions will be achieved.

In the covering essay, I address three cross-synthesizing research questions.

1. To what extent can transfer effects explain why energy use and GHG emissions in the transport sector have continued to rise?

Transfer effects are not part of official GHG accounting which is based on national demarcation. They are also not systematically included when assessing further growth in energy use and GHG emissions from transport. If we include them, transport emissions will be higher. I argue that transfer effects are not in themselves the reason for the continued rise of energy use and GHG emissions and that we should look at the mechanisms that generate transfer effects.

Gaining insight about transfer effects is crucial in order to decide which strategies or policies we should use for major reduction of energy use and GHG emissions in the transport sector. Rebound effects have addressed some of the shortcomings of the efficiency strategy applied in general in the transport sector, while trade-off effects have addressed some of the shortcomings of a change to alternative fuels and powertrains. Further, I conclude that focusing on consumption-based GHG emissions inventory is more appropriate when accounting for the real emissions associated with transport.

2. What are the similarities and differences between the three investigated transfer effects?

All three effects show that proposed solutions or the lack of understanding of environmental problems can cause environmental problems elsewhere. They call for non-reductionism research; it could be argued that transfer effects connected to transport are difficult to study via positivistic research methods, which are not suited for studying such complex and interrelated phenomena. However, transfer effects do differ in both research areas and the levels they address.

3. To what extent have such effects been overlooked in policy making, and what could be done to mitigate them?

Although transfer effects have been largely overlooked in policy making, there have been some initiatives to include them, for example, the EU biofuel directive aimed at avoiding trade-off effects and some international standards for engine efficiency for ships and planes. I believe that mitigating these effects calls for a change in how we think about economic growth and for a fresh look at the social and political reasons for increased transport volumes.

I suggest three interesting areas for further research:

Research connected to rebound effects associated with transport should shift from a focus on measuring size towards addressing underlying mechanisms. This should be done by studying rebound effects through the lenses of several disciplines.

It will be interesting to look deeper into the role that transport plays in relation to consumption-based GHG emissions and to consider how domestic transport connected to import and export used for consumption elsewhere contributes to overall transport volumes.

There is little practical policy connected to avoiding transfer effects. I suggest that we need improved knowledge of how transfer effects could be implemented into practical policy as well as the development of policies to curb transfer effects.

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SUMMARY

Transport accounts for 25 percent of global energy related greenhouse gas emissions and over half of the world's oil consumption. The energy consumption is growing at a rate higher than any other sector. The thesis addresses some of the shortcomings with current policy strategies for reducing energy use and greenhouse gas emissions in the transport sector. The thesis fosters an in depth discussion of how geographical transfer effects, trade off effects and rebound effects are present in energy and climatic mitigation strategies in the transport sector. A better understanding of this could give an improved foundation for policy makers to find strategies and actions to limit such effects and their consequences.

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